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AGRICULTURE

THE SCIENCE AND PRACTICE OF
BRITISH FARMING

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THE SCIENCE AND PRACTICE OF BRITISH FARMING

BY

JAMES A. S. WATSON, K.B.

AND

THE LATE

JAMES A. MORE

TENTH EDITION, REVISED AND ENLARGED, BY
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PREFACE TO TENTH EDITION

THIS book was originally intended as a text for students, and its primary purpose has not changed; it has, however, been increasingly used by practising farmers and, in order that it may serve their needs also, the authors have been at pains to avoid the use, without explanation, of such scientific terms as have not yet become part of our farming vocabulary.

Because of the lamented death of James Anthony More, and also by reason of ever-increasing specialization in Agricultural Science, it has been necessary to seek the collaboration of several friends and colleagues.

Mr W. J. West has again revised the sections on farm machinery, has read the whole of the proofs, and has made many helpful suggestions. Mr C. V. Dadd has covered his special field of Crop Husbandry. Dr K. L. Blaxter has revised the chapter on Animal Nutrition and Dr C. C. Thiel the section on Dairy Equipment. The late Dr D. J. G. Black, just before his death, re-edited the chapter on Poultry. Miss Eileen Handlen has again provided the Index.

A great part of the book has been rewritten and much new material has been added, especially in the section on Farm Organization and Management.

The pace of progress in farm science and technology is now such that any sizable book must inevitably be out of date, in some respect, before it leaves the press. In the present case the most important failing is with respect to various noteworthy developments in the field of farm chemicals (weed killers, insecticides, sheep dips, etc.) which occurred in the few months preceding publication.

JAMES A. S. WATSON.

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PART I

THE SOIL AND ITS MANAGEMENT

CHAPTER I

SOIL FORMATION AND NATURAL SOIL TYPES

SOIL is produced from rock by the process of weathering and by the activities of plants, animals, and man. Primitive or igneous rocks, formed by the solidification of the magma in the process of the cooling of the earth, consist of aggregates of mineral crystals which are large or small according to the rate at which cooling took place. Each mineral is a chemical compound with specific chemical and physical properties. Igneous rocks are very stable when kept in a dry atmosphere and at constant temperature, but as soon as they are exposed to changing temperatures, moisture, etc., slow processes of disintegration and decomposition set in.

The weathering of a rock is generally due to a combination of physical and chemical actions, but it seems best to consider the two separately.

Physical Weathering.—Firstly are processes that result in physical breakdown, *i.e.* those producing much the same result as if the solid rock had been blasted and the fragments ground in a hammer mill.

1. When a bare rock surface is exposed to direct sunlight it heats up rapidly and, when the sun sets, cools again very fast. Under desert conditions the daily range of temperature at the exposed surface has been known to exceed 100° F. Since the different minerals that make up a rock have different coefficients of expansion, and since the surface may become very hot while the interior is still cool (or *vice versa*), it will be clear that great internal stresses must be set up and that the rock will split and ultimately crumble.

2. Under moist temperate conditions the chief disintegrating force is that of freezing water. All rocks are more or less porous, and most have joints and bedding-planes through

which rain gradually seeps. As is well known, ice occupies more space than the water from which it has been formed, and the expansion pressure is very high; at $-1°$ C. it amounts to about 1500 lb. per sq. in. It will thus be clear why rocks, exposed to rain and to alternate freezing and thawing, must break up. If the disintegration of building stone is to be prevented the surface must be waterproofed.

3. A great part of Britain (about as far south as the Thames Valley) was covered during one or other of the glacial periods by a heavy cap of ice. Now when a great weight of ice rests upon a land surface the lowest layer is liquefied by the pressure from above, and the whole mass begins to slide almost imperceptibly downhill. The moving ice carries with it boulders, gravel, sand, etc., which grind and erode the rock surfaces lying below. Thus is produced a mass of broken material which is deposited where the ice melts. This material, called glacial drift, covers large areas throughout the cool temperate regions. Its actual nature depends on the character of the parent rock, sandstones giving rise to glacial sands or gravels, while fine-grained rocks yield a mass of soft mud containing large and small stones which is called "till," or "boulder clay," in the better and more restricted sense.

4. Under desert conditions rock surfaces are eroded by the action of wind-blown sand.

5. In wet and hilly regions the streams, by rolling stones and gravel along their courses, grind down the larger into smaller particles. A similar action is produced by tidal and wave movements along sea coasts.

Chemical Weathering.—In order to understand the chemical changes that occur in weathering we must know something of the chemical composition of the primitive crystalline rocks that form the greater part of the earth's crust. In some places such rocks form the surface layers and thus, by primary weathering, give rise to the local soils. In other places they are covered by strata of sedimentary rocks—sandstones, limestones, shales, etc.—which have been derived by previous weathering from crystalline rocks. These sedimentary rocks give rise to soils by secondary weathering. In either case the mineral matter of the soil traces back ultimately to the minerals found in the crystalline rocks.

Of these minerals the most abundant are the *felspars*, which are double silicates of alumina with potash or soda or lime or some combination of the last three. Orthoclase felspar, for example, has the formula K_2O, Al_2O_3, $6SiO_2$. It has been estimated that the felspars, as a group, constitute some 55 or 60 per cent. of the earth's crust. Felspars in general, and more especially those containing lime, weather readily.

Next in order of abundance is the group of complex silicates of iron with lime and magnesia—*hornblende*, *augite*, *olivine*, etc.—which constitute about one sixth, by weight, of the earth's crust. They are the main source of the iron compounds which occur largely in most soils.

Third, making up about an eighth of the total weight of the earth's crust, is *quartz*, which is the crystalline form of silica (SiO_2). It occurs in quite large crystals in the coarser grained igneous rocks (such as many granites) but in other cases as scarcely visible particles. It is colourless when pure, very hard, and extremely resistant to chemical change. It should be noted in passing that secondary forms of silica occur in sedimentary rocks, the flints in chalk being the most familiar.

The *micas* (3·5 per cent.) are complex silicates of potash, or of potash and soda, with alumina and a small amount of ferrous iron. They differ from the felspars in having a flaky instead of a granular structure and in being much more resistant to chemical change.

Calcium carbonate occurs only sparingly in crystalline rocks, in the form of calcite or Iceland Spar. Most of the lime that occurs naturally in soils derived from igneous rocks comes not from this source but from the breakdown of the felspars and the hornblende-augite group of minerals. Marble, limestone, and chalk are all secondary rocks made up of the skeletons of molluscs, protozoa, and other aquatic animals.

Of minerals occurring in relatively small amount the most important are the forms of *apatite*, which are double salts of lime with phosphate and some other acid radical—carbonate, chloride, etc. The apatites are the ultimate source of the phosphate of soils.

As already mentioned, the most resistant to chemical change among all the rock-forming minerals is quartz. It is only very slightly soluble in pure water and little more so in water containing carbonic or other acid. In general the quartz originally present in the native rock remains in the mature soil as grains of sand.

The most important chemical change that occurs in the whole group of rock silicates (felspars, etc.) is *hydrolysis*. This is brought about by the very slow action of rain-water, which of course contains a small amount of carbonic acid. The process is complicated and is not fully understood. Broadly, however, the alkalies and alkaline earths (soda, potash, lime, and magnesia) are split off as hydroxides and go into solution in the soil water as bicarbonates. Under wet climates and with free drainage of the material, the soda, lime, and magnesia are rapidly washed out and reach the sea, but the potash, as will be more fully explained later (p. 25), is much less completely removed. Under dry conditions some of these bases, especially soda, form various soluble salts which remain as such in the resulting soils, but the bulk of the lime is precipitated in a layer situated in the zone to which rain ordinarily penetrates. This calcium carbonate layer is characteristic of the soils of the drier regions.

Under wet tropical conditions the silicic acid, which is the other product of hydrolysis, is also largely washed out so that the main end products of silicate weathering are hydrated alumina and hydrated iron oxide—generally spoken of together as the "sesquioxides." More commonly the main residues are hydrated silicates of alumina and iron, with other still more complex substances. It will be obvious from the nature of the process that the weathering of the silicates will give rise to very finely divided material. This constitutes the *clay fraction* of the soil on which many of its important properties depend. The only other chemical change of importance is the oxidation of ferrous to ferric compounds. It is the various hydrated ferric oxides that impart to soils the common reddish and orange colours. If air is excluded from the weathered material, by lack of free drainage, this oxidation does not take place, and the soil colour is then usually a bluish grey.

It should be noted that the weathering of soils is helped to some extent by the action of living organisms. For instance tree roots penetrate any fissures that may occur in the rocks that they encounter and help in the process of disintegration. Again, the fine roots of plants excrete carbonic and other acids, which increase the solvent power of soil water. The carbonic-acid content of soil water is further greatly increased through the decay, both within the soil and on the soil surface, of plant remains. Important also is the action of earthworms which occur in all except lime-

deficient and waterlogged soils, and which pass great quantities of soil through their bodies and turn it over to the action of the weather; by their constant burrowing they increase the permeability of the weathering material to air and water, and they cause some actual breakdown of particles by the rubbing action that takes place in their gizzards. The addition of organic matter to the mineral soil, through the growth and death of animals and plants, is a very important part of the final process of soil formation and is discussed below.

Secondary Weathering.—In the case of sedimentary rocks the type of weathering will vary according to their character. Sedimentary rocks are formed from previously weathered material that has been carried away by wind or water, generally re-assorted in the process and often cemented together. In the ordinary process of denudation of a mountainous region the fast-flowing streams roll away stones of considerable size and carry gravel, sand, silt, and fine mud in suspension as well as lime and other substances in solution. As the velocity of the running water declines the coarser material falls first, and if, in process of time, it is recemented, the resulting rock will be a conglomerate or "pudding stone." There will follow, in order, materials that go to form coarse-grained and fine-grained sandstones, and those that will produce shales or mudstones. Finally, far out at sea, the calcium will be extracted by marine animals to form their skeletons, and these will accumulate to form chalk or limestone.

If a coarse-grained sandstone is cemented by calcium carbonate the immediate result of the weathering will be the removal in solution of the lime as bicarbonate, with the production of a coarse sand, but this may be altered by further weathering. In the case of chalk, the bulk of the material is removed in solution, leaving behind such other constituents as pieces of flint and quantities of fine clay. Naturally in the case of soil material that has been repeatedly weathered, such as that derived from the tertiary strata of the lower Thames Valley, the main constituents will be the end products—quartz sand, and the hydrated silicates of alumina and iron; at the other extreme, the boulder clays of Aberdeenshire, derived from granite, give soils containing many fragments of scarcely-altered felspar and mica.

Sedentary and Transported Soils.—It is worth noting that the parent material of a given soil may or may not be derived

from the underlying rock. We have already seen that a great part of Britain was glaciated, and it will readily be understood that the moving ice not only ground down the rocky material that it encountered but also moved this over greater or lesser distances. In some cases, indeed, the glacial material is derived from local rock, but in other cases the deposit has come from a considerable distance. Again, we have many alluvial soils, such as valley gravels laid down by the fast-flowing rivers of glacial times, brick earths and silts laid down along the lower reaches of these rivers or on shelving coasts, and the estuarine muds that produced the Scottish "Carses." In the larger land-masses dust carried by the wind from desert regions, and dropped in areas of moderate rainfall, have produced deep deposits of *loess*, which is the parent material of many fertile soils—*e.g.* in China and the United States. Apart from long-distance transport there is the more limited movement of material downhill. In sloping fields, especially such as have been long under cultivation, the soil at the lower end is often derived from rock lying farther up.

Soil Humus.—The weathered products of rock do not constitute a soil. Over a very wide range of temperature and moisture conditions plants establish themselves very soon after weathering begins, and the mineral material thus becomes mixed with plant remains. These remains, in process of decay, form an addition to the products of rock weathering. Moreover the decay of organic matter is caused by the activity of vast numbers of micro-organisms —bacteria, moulds and other fungi, protozoa, etc. Soil is therefore a mixture of organic and inorganic material containing a large and complex population of living things.

Where conditions prevent the complete oxidation of plant remains, dead material may accumulate until a position is reached where the greater part of the soil material is in fact organic matter. This happens wherever air is excluded by the constant presence of water. If the said water contains little in the way of bases the vegetation is restricted to mosses, certain rushes, and other particular species of plants, and the material produced is known as *peat*. A different type of material—"*Black Fen*"— is produced where reeds, sedges, and other aquatic vegetation grow and decay in lime-rich water. A third type accumulates under dry conditions where the soil is highly acid, the reason being that the organisms which cause oxidation and decay are very inactive in a highly acid medium. The material then produced

is best called *raw humus*. With the presence together of air, moisture, and lime is produced the substance known as *mild humus*. This complex substance, though it is constantly wasting by decay and whose amount can be maintained only by the addition of more plant remains, has an important influence on the structure and the fertility of the soil. Briefly a mixture of inorganic material with mild humus tends readily to form a granular mass of porous "crumbs," the individual crumbs being spongy and therefore capable of holding a good amount of water, but being separated by interconnecting spaces which admit air to the mass. Since the presence of both air and moisture in the soil is necessary to the growth of most crop plants, it follows that the production and maintenance of a good "crumb structure" in the soil is an important aim of the farmer. It should be noted that certain combinations of mineral particles are capable by themselves of being brought into good structural condition, while others are not. The agricultural or horticultural value of a soil may depend largely on maintaining a balance between the organic and inorganic constituents, but the amount of humus that is required varies with the type of mineral matter.

To exercise its proper influence in the soil the humus must be mixed with the inorganic material. Obviously if land is cultivated this admixture will be achieved. In land that is not cultivated the mixing is carried out, under temperate climatic conditions, mainly by earthworms, whose numbers and activity are closely dependent on the presence of lime in the soil.

Natural Soil Types.—It will be clear that the general character of a soil will depend to a considerable extent, and for a considerable period after weathering has taken place, on the nature of the parent material. Thus a coarse-grained sandstone will generally produce a sandy soil, and a stratum of shale a "heavy" soil. Most British soils, since they date only from the last glacial period, are relatively "young" and the influence of the parent material on the soil characteristics is marked. On the other hand, in level areas, situated in warm regions where glaciation did not occur, the soils are very old, and their nature depends less upon that of the parent rock and more upon the type of weathering that has occurred and the type of the natural vegetation. It is therefore possible to base a useful classification of the world's soils on the various types of climatic conditions under which they have been formed. While it is impossible in

this work to give an account of all the main world types, it is nevertheless worth illustrating the principles of classification by describing and explaining a number of examples.

We have already seen that the four most abundant products of weathering are: (1) the strong bases (lime, soda, potash, and magnesia); (2) silica: (3) the hydrated oxides of alumina and iron (generally called the "sesquioxides"); and (4) the clay minerals, *i.e.* the hydrated silicates of aluminium and iron and related substances. We have seen that, by hydrolysis and other processes, the strong bases are quickly broken away from their original combinations but that the subsequent fate of three of these (lime, soda, and magnesia) depends mainly on the amount of rain that passes through the soil. Where, as in Britain, the total rainfall substantially exceeds the total evaporation it will be obvious that, if the soil is freely drained, the bases will be rapidly leached out and carried away in the drainage water. One consequence is that the organic acids which are produced by the decay of plant remains will not be neutralized. Moreover the clay minerals, which behave as acid radicals will, in the absence of bases, combine with hydrogen and so come to behave like weak acids. The soils will thus all tend to be acid. Three types are recognized, *viz. Podzols*, *Grey-Brown Podzolic Soils*, and *Brown Earths*. The second, being intermediate between the other two, need not be specially described.

Podzols are produced where leaching is very heavy. As would be expected, they occur in our wettest areas. But they are also found in relatively dry districts where the parent materials have little capacity to retain moisture, *i.e.* coarse sands or gravels. The natural vegetation is coniferous forest. When this is felled the trees are replaced by heaths, bracken, gorse, wire-grass, and other highly acid-tolerant species. Again, on account of the high acidity, earthworms are generally absent, with the result that the pine needles or other plant debris decay only very slowly, and form a clearly defined surface layer of "raw humus." The relatively strong organic acids derived from the decay of this material not only remove any remaining strong bases from the top layer of mineral soil but also dissolve and carry down the sesquioxides. Thus is produced a layer of bleached material often resembling silver sand. Below this is a layer of precipitated humic material and, still lower, a horizon containing a heavy deposit of sesquioxides and generally brown, orange, or yellowish

in colour. In some cases the sesquioxide layer is cemented into something resembling a coarse-grained paving stone, which is called "iron pan." Underneath the sesquioxide layer is a horizon of parent material. It will readily be understood that the unimproved podzol is of little or no value except for such purposes as heath gardening, azalea growing, or coniferous forest. Methods of improvement are described in Ch. III (p. 61).

Brown Earth Soils, whether by reason of lower rainfall, higher evaporation, or more retentive parent material, are less heavily leached than podzols. They are not rich in bases and contain no free calcium carbonate, but they are not extremely acid. The natural vegetation is deciduous forest or scrub. The leaf mould which covers the surface is a mild humus and, since earthworms are usually present in numbers, the humus derived from the leaf fall is rather intimately mixed with the general body of the soil. There is no leaching of the sesquioxides and therefore no separation into the pale upper and deeply coloured lower layers that characterize the podzols. In general, however, there has been some downwash of the finer particles, so that the subsoil has a heavier texture than the top soil. Brown-earth soils, with moderate applications of lime and phosphate, are easily convertible into good pasture land. Many of them require only a little improvement in drainage to make them suitable for the general run of arable crops, but some are too heavy for all-round arable farming.

It should not be understood that all British soils that happen to be freely drained are deficient in bases generally or in lime. It is true that lime deficiency can occur even in soils that overlie chalk or limestone, but this is normal only where the configuration is flat. On slopes the downward slip of the soil is generally sufficient to bring lime into the upper layers. Again, in many of our soils that are derived from glacial deposits the original supplies of bases are as yet far from being exhausted. Even where no calcium carbonate is present, enough lime is set free by the weathering of felspars and other minerals to keep the base-status satisfactory. Some of our valley gravels, again, contain a proportion of limestone chips. Shallow soils on the chalk and limestone formations can be kept "sweet" by occasional deep ploughings. But though these exceptions are important it is still true that a very large proportion of British farm land can be kept fertile only by repeated applications of lime.

Peat and Fen Soils.—Where rainfall exceeds evaporation and where drainage is not sufficient to remove the surplus, the soil becomes waterlogged, oxygen is excluded, and the process of soil formation follows an entirely different course. It has already been said that the rate of decay of organic matter is dependent on the supply of bases as well as of air. But whatever the position in regard to bases, the decay of organic matter takes a different course according to the supply of free oxygen. Under anaerobic conditions change still takes place; there is considerable formation of marsh gas and carbon dioxide, which escape. But the remaining carbon compounds remain as a brown or black mass and, after the first few years, change becomes extremely slow. Where lime is lacking the final product is peat. Typical peats are formed from the sphagnum moss and other plants that grow in sour-water bogs. Peat bogs " grow " because the annual addition of fresh vegetable remains, small as this is, exceeds the annual loss by decomposition. The final product is, of course, very acid and contains only a small amount of mineral matter. Peats can be made productive of ordinary crops only by drastic and costly treatments, which are described in Ch. III (p. 60).

Where an area is waterlogged with hard water from rivers or springs, as in many lowland marshes, it supports a different type of vegetation—reeds, sedges, the larger rushes, etc. There is a relatively large annual addition of vegetable matter, which, however, contains a considerable amount of mineral substances such as lime, potash, and phosphate. The resulting soil, properly known as black fen (" muck soil " in U.S.A. and Canada), while it has certain defects (see p. 34) is much more useful raw material for agriculture than peat. Naturally, in both cases the first operation must be artificial drainage.

Gley Soils.[1]—It is a matter of common observation that many fields that lie reasonably dry in normal summers are often waterlogged or even flooded in winter. Such land can be used for summer pasturage or as hay meadow, but the herbage consists of tussock grass and other innutritious grasses, rushes, sedges, and water-loving herbs such as meadow-sweet. Where the herbage is neither grazed nor mown, alders and willows tend to establish themselves and the herbaceous plants may gradually be suppressed.

[1] " Gleying " is a term used to describe the processes that cause the reduction of the ferric oxide and also the formation of a thin glaze on the sides of the fissures.

The cause of the inadequate drainage may be the impervious nature of the parent material, *e.g.* the Oxford, Kimmeridge, Gault, Lias, or Wealden Clays that cover a large area in Midland and South-eastern England. But similar conditions occur in flats and hollows where the permanent water table lies too high and approaches or reaches the surface from time to time.

The roots of ordinary crop plants do not penetrate far into stagnant subsoil water, since this contains no free oxygen. Hence the black top soil, which contains abundant humus, is shallow. The deeper subsoil which is permanently waterlogged is of a uniform bluish-grey colour caused by the presence of ferrous compounds. Between the black top layer and the bluish-grey subsoil is a mottled layer of grey and red-orange, the mottling being due to the alternation between aerobic and anaerobic conditions, with alternate oxidation and reduction of the iron compounds to the ferric and ferrous states. Since the mottled zone represents the range of fluctuation of the water table, valuable information on drainage conditions can be obtained by examining the soil profile even when the soil is at its driest.

Gley soils in their natural condition are of low value. Autumn-sown crops are frequently " drowned out " in winter and suitable conditions for spring sowing are not obtained until the season is too far advanced. The better grasses and clovers fail to compete with the indigenous vegetation, which latter is of low nutritive value. Paradoxically, again, the better grassland plants suffer from summer drought; their deeper roots are killed by winter waterlogging, and new root growth is not rapid enough to follow the water table as it sinks in summer. When artificially drained some gley soils become extremely fertile; many reclaimed lowland marshes, where the parent material is a rich alluvial silt, are among the best of our arable areas. Where, on the other hand, the parent material is a very tenacious clay, the land is of limited value even when the necessary and costly drainage works have been carried out.

A range of soil types very different from those with which we are familiar in Britain is produced in areas where all the rain that falls is again evaporated. Here no leaching occurs, so that the resulting soils are extremely rich in bases. One of the best known is the *Black Earth* (Tshernozem), which covers a large part of the Ukraine and some part of the Prairie Provinces of Canada. The conditions are too dry for any kind of natural tree growth, and the

vegetation is a short or medium growth of grass—"prairie" or "steppe." The grass dries up and becomes dormant during the dry midsummer period. The top two or three feet of soil is a dark brown or black earth containing a considerable amount—10 or 12 per cent.—of humus, with a clearly marked crumb structure. The great depth of the top soil is explained by the fact that the grass-roots penetrate very deeply in search of water. Near the bottom of the black humic layer, or just below it, is a clearly marked horizon with a high content of calcium carbonate, marking the depth to which rain-water ordinarily penetrates. Black-earth soils have immense reserves of mineral nutrients, and, since the decay of organic matter is stopped during a great part of the year by frost or drought, there is also a large reserve of humus, which liberates a considerable amount of nitrogen during the moist warm period of early summer. The crops grown are those with low water-requirements, particularly spring wheat, barley, and linseed. Yields are closely dependent upon spring rain. Summer fallows are taken at frequent intervals, commonly every third year, in order to store up the season's rainfall. Where the parent material is clay or silt, crop yields are relatively steady, but wherever this is sandy, yields are erratic and there is risk of wind erosion.

In most of the drier regions of the world patches of saline or alkaline soil occur. Most of these occupy hollows in which seepage water accumulates, during wet periods or at the time of the spring thaw, and is later evaporated. Such patches, owing to the high accumulation of sodium salts (chloride or sometimes carbonate), are sterile.

As an example of a soil produced under the other extreme of climate we may mention the laterite soil that is formed under very wet tropical conditions beneath a growth of evergreen tropical forest. Leaching is very heavy, so that not only are the strong bases removed but also the silicic acid set free by the hydrolysis of silicates. Laterites, owing to their high sesquioxide-content and relatively low content of true clay, have a less markedly acid reaction than temperate soils of correspondingly low base-content. The organic matter added to the surface by the leaf-fall is very rapidly decomposed, partly because of the warm humid conditions and partly through the activity of termites. The lack of humus and the high content of ferric oxide account for their characteristic red colour. Owing to the intensity of the weathering processes

laterites, where they occur on level sites, are of immense depth. The texture is generally friable and granular rather than clayey. The luxuriance of the natural vegetation gives a very false impression of the fertility of the soil. The fact is that, under natural conditions, the very small reserves of plant food are very rapidly turned over. When shallow-rooting annual crops are substituted for trees, and where fertilizers are not used, the productivity of the soil declines very rapidly.

CONSTITUTION AND GENERAL PROPERTIES OF SOILS

Soil and Subsoil.—We have seen that natural soils that have been long undisturbed are composed of rather clearly defined layers or "horizons." Soil scientists distinguish three main horizons—*viz.* the uppermost (A), from which material has been removed by leaching; the second (B), in which has been deposited some of the material removed from (A); and a third (C), which consists of the parent material, *e.g.* the partly disintegrated rock. These main horizons are divided as required by the character of the soil in question; for instance, a typical podzol, such as has been described above, would be divided as follows:—

A_0, Raw humus layer.
A_1, Mineral soil containing dark-coloured humus.
A_2, Mineral soil bleached by removal of sesquioxides.
B_1, Dark-coloured layer containing deposited humus.
B_2, Yellow or rusty layer containing the precipitated sesquioxides.
C, Parent material.

It will be easily understood that such a natural structure, developed during centuries, will be completely destroyed when the soil is repeatedly cultivated, and even by a single ploughing. On the other hand a new structure develops under tillage in which there is a more or less sharp distinction between the top soil (or soil proper) and the subsoil. The most obvious distinction is in colour, the change taking place in arable land at about the usual depth of ploughing and in grass at the limit of penetration of the mass of grass roots. The top soil is dark because of its high content of decaying vegetable matter (humus) while the subsoil varies from reddish or yellowish to a pale grey tint. Another usual difference is that the top soil is coarser grained than the subsoil,

the difference being caused by the washing down of a proportion of the finer clay and silt particles; but in fertile limey soils this tendency is counteracted by the action of earthworms, which produce, by their casts, a continuous top-dressing of fine soil brought up from below. In general, again, the top soil will be richer in nitrogen and phosphate than the subsoil, since manures and fertilizers are largely held in the former; but the subsoil may frequently contain more potash. Counts of micro-organisms show, as would be expected, much higher numbers in the soil than in the subsoil.

Soil Particles.—Typical soils (excepting peats and black fen types) are composed largely of particles and fragments of mineral matter. We must remember that these particles are not by any means all free, one from another—indeed it is obvious that they are often bound together to form clods or crumbs. Nevertheless the character of a soil depends very much upon the sizes of the ultimate particles of which it is composed. If, by suitable means, we break up the clods and crumbs of a soil, pick off the stones and remove the small gravel by means of a 2-mm. sieve, the remaining fine material may be sorted out into size groups. The largest may be separated by sieving but the remainder are separated by sedimentation. The size groups as now distinguished by soil scientists in most countries are:—

	Diameter
Coarse sand . . .	2·0 to 0.2 mm.
Fine sand . . .	0·2 to 0·02 mm.
Silt	0·02 to 0·002 mm.
Clay	less than 0·002 mm.

The wide variation in mechanical make up that is encountered among British soils may be illustrated by the following mechanical analyses.[1]

	Heavy Loam, Caernarvon	Medium Loam, Monmouth	Light Loam, Caernarvon	Coarse Sand, Cheshire
Coarse sand .	8·3	9·3	21·0	52·0
Fine sand .	17·8	43·9	44·7	32·4
Silt . .	34·0	23·4	16·0	7·0
Clay . .	39·9	23·4	18·3	8·6

[1] From A. D. Hall, *The Soil*, Fifth Edition, by G. W. Robinson, 1945.

An important distinction is to be drawn between sand and silt on the one hand and clay on the other. The coarser fractions in general form the "skeleton" of the soil. They generally consist of clearly defined particles without colloidal properties—*i.e.* they do not imbibe water and swell or become plastic when wet, nor bind together into hard clods as they dry. They do not enter into combination with the soil bases. Only rarely do we find any highly reactive material in the form of large particles, and then generally in those classed as silt.

Clay.—Apart from humus, which is discussed below, the clay fraction very largely determines both the physical and chemical characteristics of the soil. Some of the properties of clay arise from the enormous area of surface presented by a material that is so minutely divided; the total surface area of the particles in a cubic foot of clay runs to several acres. Again, clay possesses certain of the properties that we associate with colloids such as gelatine. When a small lump of dry clay is wetted it swells by absorbing water; when the water is dried out the clay again contracts. This explains the familiar fact that clay soils open up wide and deep cracks as they dry out in summer. Clay becomes plastic if it is moved when wet, can be kneaded into any shape, and retains this shape on drying. The clods that are formed when a clay soil dries may be so hard that they cannot be broken with ordinary implements.

It should be noted that clays with a high ratio of silica to sesquioxides have more pronounced colloidal properties than such as are found in the tropics, in which the proportion of sesquioxide is high and that of silica low.

Colloids when dispersed in water are in what is called the "sol" condition, and when the particles aggregate together they form a "gel." If a drop of turbid clay water be examined under a high-power microscope it will be seen that the particles are in rapid "Brownian" motion, but if a drop of acid is added the particles move together to form little clots. The formation of these clots is called "flocculation," and their redispersal is called "deflocculation." Something like this occurs under field conditions. Thus if clay remains long wet, and especially if it is disturbed when there is enough moisture to make it plastic, it is deflocculated and cannot then be crumbled. Exposure to frost and thaw, with the addition of lime, acids, or neutral salts, all tend to bring about the desirable condition of flocculation; but alkalies

cause deflocculation, and salts, such as sodium chloride or nitrate of soda, by yielding free alkali on hydrolysis, are therefore harmful. The alkali residues that accumulate after frequent applications of nitrate of soda produce a very sticky condition in the soil, and an even more marked effect, which may take years to clear up, is produced when a clay soil is flooded with sea-water. The point is that the clay particle behaves as a weak acid radical which can enter into combination with bases (sodium, calcium, etc.) or hydrogen. Thus we can speak of "calcium clay" which readily forms crumbs and "sodium clay" which has a very high capacity to take up water and then forms a sticky and impervious mass. This cannot be brought into condition suitable for plant growth except by such means as the application of gypsum and exposure to leaching. The presence of a large proportion of "hydrogen clay" implies an acid reaction, a condition that is unfavourable to the growth of most plants (see p. 26). The important property of clay and other colloids of absorbing and retaining potash, ammonia, and other ions is dealt with later (p. 25).

The power of crumb formation by clay soils is very important in relation to the growth of crops. So long as the clay particles are aggregated into crumbs the soil behaves as if it were composed of quite coarse particles. Water percolates freely through the relatively large spaces, and air is drawn in as the water escapes below; but water is held in considerable quantity within the crumbs themselves. Crumb formation on heavy soils, besides being greatly facilitated by the addition of lime, is also aided by the presence of humus. At the time of writing research was proceeding on the use of synthetic plastics as "soil conditioners," and also on the use, in promoting crumb structure, of the naturally occurring mineral vermiculite. Such materials, while likely to be useful in the preparation of seedling and potting composts, and possibly also in glass-houses, may possibly prove too costly for the farmer.

Humus.—All soils contain a greater or smaller proportion of complex organic substances, derived from plant roots and other plant and animal remains, which are in process of conversion into simpler substances. This organic matter may be roughly divided into (1) material in which decomposition has not yet proceeded far, which retains its cell structure and which may be called "fresh" organic matter, and (2) the dark-coloured mixture of

partly decomposed material and decomposition products to which the term humus properly belongs.

Fresh organic matter has an important influence on the texture of the soil. When added to heavy clay it improves aeration and drainage so that its effects, in moderate quantity, are beneficial; when added in quantity to sandy soils it tends to increase their porosity, which is already too great for the best results. Until its decomposition has gone some way its presence therefore tends to accentuate the ill-effects of drought.

True humus, which consists of the colloidal residue of organic matter that has been attacked and partly decomposed by bacteria and fungi, has far-reaching effects on soil texture and fertility. Whenever it is present in considerable quantity it imparts its black or dark-brown colour to the soil, and since dark-coloured materials absorb more of the sun's heat than light-coloured ones, its presence tends to raise the soil temperature. Moreover, in well-aerated soils humus is constantly undergoing oxidation, with liberation of simple compounds of nitrogen which can be taken up by plant roots. Most important is the fact that humus has many of the properties of mineral colloids—it increases the soil's power of retaining moisture and it absorbs and holds plant nutrient substances.

When organic matter is added to light soils the resulting humus tends to bind the mineral particles into crumbs which absorb and hold water like miniature sponges. Like clay, humus can give cohesion to soils that would otherwise fall into their constituent particles; but unlike clay, it does not give the soil plastic properties nor does it "set" to a hard consistency on drying. If lime be also present, humus aids flocculation of the clay colloids and promotes improved texture; but if lime is absent, humus will rather add to the stickiness of a clay soil.

It has already been noted that "raw" humus in the absence of lime imparts to the soil a strongly acid reaction which is unfavourable to the growth of most higher plants. It should also be pointed out that the presence in the soil of both oxygen and lime, which are essential to the healthy growth of most crop plants, tends to promote bacterial action and thus causes the oxidation and disappearance of humus. Hence if a soil is to be productive a relatively high rate of loss of humus is inevitable, and repeated applications of organic matter have to be made if the humus content is to be maintained at a high level. The level

to be aimed at depends on a number of factors, such as the nature of the mineral fraction of the soil, the local climate, and the types of crops intended to be grown. The means of maintaining the humus content include the use of dung and composts and the ploughing in of grass swards and "green manuring" crops.

Pore-space and Density.—It is obvious that a soil, consisting of particles of solid matter, must contain a considerable amount of pore-space. The amount is indicated by comparing the "apparent density" of an air-dry soil with the true specific gravity of its particles. Neglecting such soils as contain much organic matter, which are relatively light, common figures for apparent density run from about 1·1 to 1·5 (or say 70 to 95 lb. per cub. ft.) compared with a true specific gravity of the particles of about 2·6.

The following figures [1] give the apparent density, weight per cubic foot, and percentage pore space of a number of soils. The last column shows the total weight of top soil (*i.e.* of the top 9 in.) in tons per acre.

	Apparent Density	Weight, Lb. per Cubic Foot	Percentage Pore Space	Top Soil per Acre, Tons
Heavy clay .	1·062	66·4	57·0	963
Light loam .	1·222	76·4	51·0	1107
Light sand .	1·266	79·2	49·0	1143
Sandy peat .	0·782	49·0	68·5	705

The pore space is not directly dependent upon the size of particles since, with the closest possible system of packing, the same percentage pore space is obtained with spheres of all sizes—*e.g.* small shot or marbles. Obviously, if the soil is composed of particles of varying size the pore space may be less than in a soil of uniform particle size, since the smaller particles fit into the spaces that occur between the larger. Again, the pore space will obviously depend on the arrangement of the particles; indeed it can be shown mathematically that, with spherical particles, the pore space may vary between a minimum of 25·95 per cent. and a maximum of 47·64 per cent., according to the mode of arrangement. It is a well-known fact that when we dig a hole the excavated soil may be considerably more or less than the amount

[1] From A. D. Hall, *The Soil*, Fifth Edition, by G. W. Robinson, 1945.

required to refill; in other words, it is rarely that the soil can be disturbed and re-packed without alteration of the pore space in one direction or the other.

It will be seen that, in the first three soils in the table above, the pore space is in inverse proportion to the size of the particle. This is a usual finding, one explanation being that, whereas the weight of an individual coarse sand particle is sufficient to ensure fairly close packing, that of the small clay or humus particle is not sufficient. Another explanation is that heavy soils have a marked tendency to form aggregates or clods, with spaces not only between the individual particles but also between the aggregates.

Soil Structure.—Coarse sandy soils show very little cohesion even when wet, and as they dry fall into their constituent particles. Water percolates quickly down their pores and carries down in solution not only nitrates but also considerable amounts of potash. The addition of organic matter binds together the particles, but its effect is short-lived because, under the highly aerobic conditions that prevail, humus is quickly destroyed by oxidation.

Again, a soil composed mainly of sand and silt, with little clay, fails to form stable aggregates so that, for example, an autumn seed-bed is broken down and closely packed by the winter rains; on drying in the following spring a surface crust may form, aeration of the soil is restricted, and root development is therefore impeded. The farmer expresses the difficulty by saying that such a soil will not "hold its clod."

The other extreme may be illustrated by a heavy clay soil, under pasture, in time of drought. Its high colloid content gives the soil great cohesion and causes it to shrink both vertically and laterally, resulting in wide cracks, widely spaced. Rain, when it comes, flows down these cracks to the subsoil, failing to wet the root zone, so that the grass makes a very slow recovery.

Where, however, colloidal material is present in moderate amount, and more particularly where there is a good supply of humus as well as colloidal clay, the skilful cultivator can produce any one of a variety of different structures; for example, he can have his land, during the winter, in unbroken furrow, and so ensure that the winter rain will penetrate easily to the subsoil; he can have the land in "summer clod," *i.e.* in hard lumps that dry out so completely that enclosed pieces of plant tissue are killed

by desiccation; or again, he can have a seed-bed of any desired degree of fineness with, as is often to be desired, the coarser clods above and the finer crumbs below.

Unless there is a variety of materials in the various soil horizons (in which case they can be mixed by deep ploughing) the cost of achieving a worth-while change in the soil texture is usually prohibitive. Exceptionally, however, this is possible by claying, marling, or warping (see pp. 60 and 80).

Soils that have enough colloidal material to give a clearly defined structure are usually plastic within a certain range of moisture-content. Above a given water-content soil will form a liquid; below this level, and down to the lower limit of plasticity, the soil "pastes," and does not crumble when it is worked. The *plasticity number* of a soil is the difference between the moisture-contents at the upper and lower levels of plasticity—*e.g.* if a soil begins to show the properties of a liquid at 55 per cent. moisture, and shows signs of crumbling when worked (or stirred with the foot) at 35 per cent. moisture, its plasticity number will be 20. Generally speaking, heavy and markedly plastic clays have plasticity numbers over 20, and feebly plastic soils have numbers below 10. Many useful soils fall within the 10 to 20 range.

A soil may quite properly be forked over, or turned over by means of a suitable plough, when it is considerably above the lower plastic limit. Indeed, if it is specially desired to avoid crumbling, ploughing is best done under such conditions. But any rubbing, scraping, or squeezing action, such as that produced by harrowing or rolling, must be avoided until the moisture has fallen below this limit, otherwise the soil will "paste" and "puddle" instead of crumbling.

Soil Moisture.—Since poor crops are more often due to unsatisfactory moisture conditions in the soil than to any other single cause it is necessary to consider the subject of soil moisture in some detail. The soil may be supplied with water by irrigation, by springs, by seepage from higher ground, or it may draw moisture from a shallow water table. Again, some moisture is received by condensation of water vapour from the atmosphere. Generally speaking, however, the only important source of supply is rain or snow.

Some of the facts about the behaviour of water in soil may be illustrated by simple laboratory experiments. We may, for instance, take four glass cylinders, with perforated bottoms, and

fill each with different grades of particles such as medium and fine gravel, coarse and fine sand. If the bottoms of the cylinders are closed and water is poured in from above until it reaches the top, the amount of water added will measure the pore space in each case. If now the bottoms are opened water will begin to flow out, most quickly from the coarse gravel and most slowly from the fine sand. But it will be found that not all the water that was poured in will have drained out even after several days. If the drainage water from each cylinder is measured, the quantity retained in each case can be found. This will be greatest in the case of the fine sand and least in the coarse gravel. The difference is partly to be accounted for by the larger surface area to be wetted in the case of the finer material, but partly also by the fact that small soil pores, like fine capillary tubes, exercise a stronger hold on water than large pores or wide tubes.

If we refill the cylinders with dry material and, instead of wetting them from above, stand them in shallow water, we find that there is some upward movement of water in each case; in other words, the force of surface or capillary attraction can not only hold water against the force of gravity but can also move water upwards. In the case of the coarsest material the movement is practically instantaneous and very small, whereas in the finest the movement, while ultimately going a long way, will be relatively slow to begin with and will become progressively slower with increasing distance. There has been a good deal of dispute on the question as to how far the requirements of plants can be met by water that is raised by capillary action from the water table below. In very fine-grained material the distance is very great, but it seems that beyond a height of more than two or three feet the rate of movement is so slow that the quantity moved in a period of drought must be negligible.

From what has been said earlier it will be clear that a quantity of gravel or sand cannot be regarded as a true large-scale model of the soil. Natural soils contain not only crystalline particles but also particles of colloidal clay and humus, and others of hydrated ferric oxide, which all imbibe water and swell in the process, as does a piece of wetted gelatine. In ordinary soils, under field conditions, the greater part of the soil water is so held, *i.e.* as "imbibitional" moisture. If the colloids are "puddled" or dispersed they block up the pore spaces between the mineral particles so that water ceases to move at all. Imbibitional moisture,

as would be expected, is very strongly held against the force of gravity, but if it be present in large amount, some can be drawn off by plant roots.

Thus far we have seen that water occurs in the soil in three forms, *viz.* (*a*) *imbibitional*, (*b*) *capillary*, which is held, by surface attraction, as a thin film surrounding the particles and as a filling of the finer pores, and (*c*) *gravitational*, which is in process of percolating downwards under the force of gravity. A fourth is *hygroscopic* moisture, which must be shortly discussed. If an oven-dried soil is exposed to ordinary air it absorbs moisture and increases in weight by an amount that depends on the humidity of the air, the temperature, and the nature of the soil itself. Quartz sand takes up only a trace of hygroscopic moisture, which is held as a film of molecular thickness on the surface. Colloidal material, like humus and clay, as well as ferric oxide, are by contrast highly hygroscopic. A peaty or highly sesquioxidal soil may collect as much as 20 per cent. of its own weight of moisture from a not very humid atmosphere.

As has already been pointed out, not all of the water present in soil is capable of being drawn upon by the roots of plants. The moisture-content at which a particular soil ceases to yield up water to the plant is termed its *wilting coefficient*. The actual point varies in the case of individual plant species but is fairly uniform as between the ordinary crops. Wilting begins before the water-content of the soil has reached the hygroscopic limit—*i.e.* there is some moisture, in addition to hygroscopic moisture, that is not available. The following figures by Heinrich illustrate the point:—

	Water per Hundred of Dry Soil	
	Hygroscopic	At "Wilting Point"
Coarse sand	1·15	1·50
Sandy garden soil	3·0	4·6
Fine sand with humus	3·98	6·2
Sandy loam	5·74	7·8
Chalky loam	5·2	9·8
Peat	42·3	49·7

It will be seen that, for the middle range of soils, the second figure is about 50 per cent. higher than the first. A scientific

measure of the wetness of the soil has been devised and is expressed in terms of a *p*F scale. Two soils of the same *p*F are in moisture equilibrium if placed in contact—*i.e.* neither draws moisture from the other. If one were a peat and the other a sand their actual moisture-contents would be very different, but each would yield up moisture to a growing plant with the same degree of ease.

Despite a great deal of research on soil-moisture problems many questions are still controversial, and there is a considerable amount of conflict in regard to certain matters between scientific hypothesis on the one hand and, on the other, traditional practices and the beliefs on which these are based. Thus the farmer likes to horse-hoe his roots as soon as he can see the rows, whether or not there are weeds to be killed. He believes that, by producing a "mulch" of dry, loose surface soil, he protects the lower soil from loss of moisture by evaporation. Gardeners are even more insistent upon the benefits of hoeing in dry weather. Scientific experiments, on the other hand, suggest that, unless there is a water-table quite near to the surface, the upward movement of water, and therefore the loss by evaporation, will be negligible whether or not the surface is hoed. It would, however, seem that there is a real foundation for the belief in the efficacy of hoeing under certain circumstances. If the soil surface is allowed to form a crust, gaseous exchange between the soil and the atmosphere must be impeded and the carbon-dioxide content of the soil air may rise to a level that restricts root activity. In such a case the plants would in fact suffer from drought. Again, some farmers and gardeners roll in or "tread in" small seeds in the belief that moisture will rise in the firmly packed soil and wet the seeds sooner than would otherwise happen; but again, scientific experiments throw doubt on the efficacy of consolidation as a means of bringing up soil moisture. It will, however, be obvious that a firm seed-bed is required, under relatively dry soil conditions, in order to ensure contact between the seed-coat and the moisture film that surrounds the soil particles. The evidence from scientifically controlled experiments is to the effect that tillage operations beyond those necessary (*a*) to allow rain to penetrate the soil, (*b*) to assure germination of seeds and the establishment of seedlings, (*c*) to break a surface crust, and (*d*) to kill weeds, are so much waste of effort.

Soil Temperature.—The usefulness of a soil is greatly

influenced by its mean, maximum, and minimum temperatures. Most of the heat received by the soil comes from the sun, but it also has its temperature raised by conduction from the warm interior of the earth and by oxidation of organic matter. On the other hand, heat is continually being lost by radiation into space and dissipated by the evaporation of moisture. Now the amount of solar heat received by any soil depends on its latitude and elevation, being greatest near the equator where the heat rays are most concentrated and at low elevations where dense and moist air bring about a maximum of heat retention. The aspect of the soil is also important because land facing the sun receives a greater concentration of heat rays, and in the Northern Hemisphere the soil temperature is always highest on land sloping to the south. Colour, too, has an influence on heat-absorbing power. Light-coloured soils reflect much of the energy of the sun back into space, so that dark soils are always warmer. Again, the amount of heat necessary to raise the temperature of dry soil by a given amount is less than that required to elevate the temperature of a similar quantity of water to the same degree; in other words, the specific heat of soil is less than that of water. It follows that when heat rays fall on a mixture of soil and water, the greater the quantity of moisture present the less will be the rise in temperature. Thus peaty or clay soils, with their high water-content, are cold and late. Again, the greatest amount of evaporation goes on in wet soils, and as water absorbs a great deal of heat in its change from the liquid to the gaseous state, soils having much moisture will be kept considerably cooler than those that are well drained and have an open texture.

It is worth noting that root activity and growth, in many crop species, can proceed when the soil temperature is still too low to permit of humification and nitrification. This explains the common occurrence in spring of symptoms of nitrogen starvation (especially a pale yellowish colour) in winter corn and grass. The condition tends to be most acute when a slow spring follows a wet winter. The remedy is, of course, to apply nitrogen in immediately available form.

The local incidence of frost is important, especially in relation to the production of fruit, early potatoes, and certain vegetables. The point is, indeed, the temperature of the lower air rather than of the soil, but it may be dealt with in this place.

In a general way soil and air temperatures decrease with

increasing altitude. Locally, however, the severest frosts occur in hollows and valley bottoms. In extreme cases a particular area has a traditional reputation as a "frost pocket." In other cases, where only frost-hardy crops have been grown in the past, the position is realized only after fruit trees or other susceptible plants have been established.

The occurrence of damage by night frosts to crops in hollows, when the adjoining slopes escape, is explained as follows: the frosts are the result of excessive radiation, which occurs on still nights of clear skies. The soil surface cools rapidly and, in turn, chills the air lying immediately above. The cold air thus produced is relatively dense, and therefore flows down slopes and accumulates in "pools," which have often a clearly defined and almost level surface. The avoidance of sites with poor "air drainage" is thus very important in the case of crops that are susceptible to frost damage. In some cases air drainage may be improved—for example, by the removal of tall hedges or belts of woodland. In other cases the stream of cold air, moving down a slope, may be diverted from the area immediately below by interposing a tall hedge or a belt of trees which would conduct the air, at a lesser pace, into an area where it would do less harm—for example, a valley bottom that is under pasture.

Absorption.—Any salt, acid, or base dissolved in water dissociates more or less to give positively charged ions or cations and negatively charged ions or anions. In the case of salts the cations are metals and the anions acid radicals; with acids the cations are hydrogen and the anions are acid radicals; with bases the cations are metals and the anions hydroxyl (OH) groups. The ammonium radicle (NH_4) behaves like a metallic ion.

The analyses of drainage waters show that the cations calcium, magnesium and sodium, and the anions nitrate, sulphate, chloride, and bicarbonate are lost in large quantities from the soil. On the other hand, only a small amount of potassium and mere traces of ammonium and phosphate appear in the drainage. The soil particles, particularly the mineral and organic colloids, possess absorptive properties; that is to say, they can hold, by virtue of their large surface and electrical charges, various cations including hydrogen. When such particles come in contact with a solution, part of their absorbed cations are replaced by cations from the solution. Consequently, the addition of such salts as ammonium sulphate or potassium chloride to a soil will result in the absorption

of ammonium or potassium ions and the displacement of calcium and other cations. The displaced ions come into solution and may be lost in the drainage water. In normal soils the ammonium ion is converted rapidly by micro-organisms into nitrate (see p. 42), and an application of sulphate of ammonia may thus produce a concentration of both nitrate and sulphate ion in the drainage. If a growing crop is present, however, the nitrate is likely to be taken up by the plant roots. Anions are not " absorbed " by the soil. The reason why only traces of phosphate are found in drainage water is that phosphate is precipitated as a sparingly soluble calcium compound or, in the case of an acid soil, as an insoluble iron or aluminium compound. The other anions, such as chloride and sulphate, form soluble salts with cations of the soil solution.

Soil Reaction.—When the absorptive capacity of the soil is satisfied by metallic cations the soil is said to be *saturated*, but when a proportion of the absorbed cations consists of hydrogen the soil is said to be *unsaturated*. The degree of unsaturation, which may be regarded as the absorbed hydrogen ions expressed as a percentage of the total absorbed cations, is a most important characteristic of the soil. As a rule soils like our own, which have developed under cool humid conditions, are more or less unsaturated because of their long exposure to leaching. This is due to the fact that water percolating downwards to the drains contains carbonic acid, " humic " acids from decomposing organic matter, and small amounts of sulphuric and nitric acids from rain and organic sources, and that the hydrogen ions of these acids tend to displace the metallic cations of the soil complexes. The loss of lime from a calcium-rich soil may be from 2 to 5 cwt. per acre per annum and much more in those industrial areas where the rain is polluted with sulphur fumes. In course of time a soil may become so unsaturated as to show all the characteristics of " sourness." Once a high degree of acidity has been developed, however, soils retain their small amounts of calcium very firmly.

Unsaturated colloidal particles behave like weak acids, for although they are almost insoluble in water, they are able to dissociate to a sufficient extent to provide free hydrogen ions in solution. Now there are two distinct aspects of soil acidity: the first, which may be termed the *intensity* of acidity, is the concentration of hydrogen ions in solution and is measured in terms

of pH [1]; the second, termed the *quantity* of acidity, is the whole of the absorbed hydrogen ions, which, although not completely dissociated, are capable of being displaced by metallic cations. These two measures of acidity do not necessarily bear any relationship to each other. The former is active and affects the suitability of the soil for plant growth; the latter is, in a sense, potential rather than active. The remedy for both is to apply lime so that the calcium may displace part of the absorbed hydrogen and so reduce the degree of unsaturation and decrease the acidity.

The greatest degree of acidity met with in natural soils is about pH 4. Greater extremes are known, but are generally due to the presence of strong mineral acids—generally sulphuric acid which may be brought down in considerable quantity by rain in areas near to steel works, factories, etc. Alkalinity above pH 8·5 is generally due to the presence of sodium carbonate (black alkali), which occurs only in the soils of semi-arid, or desert regions. Few British soils are more alkaline than pH 7·5, a figure that implies a high content of lime.

The pH of a soil may be roughly measured by a colour test carried out in the field. Thus the B.D.H. standard mixed indicator when mixed with the soil solution gives a colour ranging from blue (pH 7·5) through green and yellow to red (pH 4). A colour chart enables the colour of this solution to be matched to the nearest tint on the scale, and the pH for each tint is given. The results of such tests, while useful, should not be used as a basis for recommendation in regard to the quantity of lime that the soil requires.

Many experiments and observations have been made in order

[1] Any aqueous solution of a salt or an acid or a base contains hydrogen and hydroxyl (OH) ions, and the product of the concentration of hydrogen ions (C_H) and the concentration of hydroxyl ions (C_{OH}) is always equal to 10^{-14} gram ions per litre at 20° C. In pure water with a neutral action,

$$C_H + C_{OH} = 10^{-7}, \text{ or, } 0{\cdot}0000001.$$
$$pH = -\log C_H = 7.$$

In an acid solution C_H is greater than C_{OH}, that is, the pH is less than 7; in an alkaline solution C_H is less than C_{OH}, *i.e.* the pH is greater than 7. The pH scale therefore runs from 0 to 14; from 7 down we get increasing acidity and from 7 up we get increasing alkalinity. The pH values for normal arable soils in this country generally lie between 5·5 and 7·7, but acid peats may have a pH value as low as 3·5 and alkaline soils in semi-arid regions may have values of above 9. It has been suggested that soils might be grouped according to their pH values as follows: up to 5, very acid soils; 5 to 6, acid soils; 6 to 7, slightly acid soils; 7 to 7·5, slightly alkaline soils; 7·5 and upwards, alkaline soils.

to determine the *p*H range best suited for various field crops, the values at which crops fail, etc.[1] Although the *p*H of the soil is merely an index of other properties and may fluctuate considerably with changing conditions, such figures may nevertheless be of practical value for the district in which they were obtained. A comparison of figures secured in different parts of the country, however, shows that there is not sufficient agreement to warrant their general use.

The failure of crops on " sour " land may be due not directly to acidity but to indirect influences. Thus the acidity may become sufficient to bring iron and aluminium into solution, and these may prove toxic to plants or may precipitate all the available phosphate. Again, a very acid soil may possess such a high ratio of absorbed hydrogen to calcium as to cause plants to suffer from calcium starvation, and so on.

There is also a relationship between rainfall and the effect on crops of soil acidity. This effect is relatively severe in areas of low rainfall, and failures may occur, in dry years, on land that crops well in wet seasons.

The *quantity of acidity*, or total amount of unsaturation, is measured by the amount of calcium or other base which is required to make the soil saturated. In practice this is not determined directly, the " lime-requirement " being estimated by observing the amount of calcium which is absorbed by the soil under certain standard laboratory conditions. Usually the sample of soil is treated with a solution of a calcium salt and the amount of calcium absorbed from the solution is determined. A better method is to add increasing quantities of lime-water to different portions of the soil and observe the effects of these additions on the *p*H value. In this way it is possible to calculate how much lime is required to bring the soil to any particular *p*H.

It is quite possible to have soils of the same *p*H value but possessing different " lime-requirements," and *vice versa* This is on account of the differences in the quantity and nature of their colloidal materials. For instance, let us suppose that a given soil

[1] Morley Davies gives the following as the critical *p*H values at which crops fail :—

Alsike clover	5·6	Swedes and cabbage	4·9
Red clover	5·5	Kale	4·5
Sugar-beet, mangolds, and barley	5·3	Ryegrass	4·3
Wheat	5·1	Oats	4·2
		Potatoes	4·0

has a pH of 4·5 and a "lime-requirement" of 6 tons per acre. If the soil is mixed with an equal quantity of chemically inert substance, such as quartz sand, the pH will remain at the old figure, whereas the "lime-requirement" would work out at only 3 tons per acre.

As already mentioned, the unsaturated colloidal material acts as a weak acid; it therefore possesses a buffer action and prevents a rapid change in the pH value on the addition of acid or alkali. Consequently, a soil possessing a large amount of colloidal material may require a large application of lime to bring its pH value towards neutrality. Such a soil may nevertheless be in less serious need of lime than a sandy soil which, although having a much higher degree of unsaturation, actually shows a smaller "lime-requirement" owing to its smaller total of colloidal material and absorbed hydrogen. The quantity of lime that should be applied must also depend on the crop that is to be grown, and its estimation in practice demands a careful study of all the conditions in each case. Actually, the principal crops of our northern and wetter districts all do best on soils that are somewhat acid; some fail on alkaline soils.

There are soil advisory services which deal with soil samples and among other functions issue recommendations regarding "lime-requirements." For this purpose the pH is measured electrometrically and a measure is made of the amounts of calcium hydroxide required to change the pH to suitable values such as 6 or 6·5 or even 7, according to the crops grown. These quantities are then converted into hundredweights of lime per acre.

The following figures illustrate clearly the varying effects of

Year	Crop	Yield per Acre	
		Chalked	Not Chalked
1931	Potatoes (tons)	12·0	10·6
1935	Wheat (cwt.)	39·3	31·2
1936	Sugar-beet (tons)	13·4	1·6
1938	Peas (cwt.)	40·4	13·3
1941	Oats (cwt.)	46·9	49·6
1942	Lupins (cwt.)	17·1	17·1
1943	Wheat (cwt.)	34·8	16·3

soil acidity as between different crops. They refer to yields on the limed and unlimed portions of a field of originally acid sandy

land (pH 4·8) at Tunstall in Suffolk. Half the field was chalked at the rate of 5 tons per acre in 1927 and no further lime has been applied.

The unlimed plot, presumably, became progressively more acid in the period between 1927 and 1943.

FARM SOILS AND THEIR CHARACTERISTICS

In most soils the largest group of constituents is mineral particles falling within the four groups defined on page 14, *viz.* coarse sand, fine sand, silt, and clay. Moreover, the great majority of soils contain considerable amounts of all four fractions. The particular blend may give a texture ranging from extremely "heavy" to very "light." The terms commonly employed are heavy clay, clay, strong or heavy loam, medium loam, light or sandy loam, sand, and "blowing sand." The farmer's "heavy clay," however, may contain a considerable quantity of one or more of the coarser fractions, and even a "blowing sand" will usually contain some clay or silt.

Occasionally the preponderance of the silt fraction produces characteristics different from those associated with the mixture of size groups that constitutes an ordinary loam, and the term "silt loam" is then used. Very occasionally, too, we find soils (generally derived from a mixture of two distinct alluvial deposits) in which the coarse sand and clay fractions preponderate, while particles of the intermediate groups are very few. In this case the behaviour is different from that of an ordinary loam, and the term "sandy clay" is sometimes used.

Occasionally the proportion of stones is large enough to influence the behaviour of the soil. The term "brash" or "stone brash" is commonly used to describe soils on the oolitic limestone whose stoniness is their outstanding characteristic. Again, where the proportion of gravel, or the presence of a gravelly subsoil, affects the soil's capacity to withstand an ordinary drought, terms like "light gravelly loam" may be usefully applied. Gravelly soils are often described as "hot" or "burning."

Next, the proportion of organic matter may be so high as to require mention. In this case terms like "peaty loam" or "sandy peat" are used. "Black-top land" is a term used in Scotland with the same implication.

Again, the lime-content may be so high as to affect the soil's

characteristics. " Marl " and " clay marl " are terms generally used.

Finally, whenever the soil overlies rock, the depth at which the rock lies is a material point.

Naturally a full description of a soil, covering its depth, mechanical analysis, structure, reaction, humus-content, etc., is valuable. It should also be mentioned that a soil survey of parts of this country has been made and in these areas it is sufficient to indicate that a particular soil belongs to a named soil series whose description has been published. But the local farmer's description of a given soil may convey a great deal if his terminology is understood. Descriptions like "thin sticky brash," "cold boulder clay," "hot and hungry gravel," or "good honest loam" convey the essential information in each case. The following notes deal with the agricultural uses and characteristics of the main classes.

Clay soils contain more than 20 per cent. of clay and a correspondingly high proportion of other fine soil particles; their texture prevents the free movement of air and water; indeed, they possess to some extent most of the qualities of pure clay. They must not be worked when they are in a wet condition since they become puddled and impervious to water, dry into rock-like clods which cannot be reduced to the fineness required for a seed-bed, and are rendered useless for the rest of the season. If the clay land is under grass it cannot be stocked in wet weather as treading " poaches " the surface, prevents the passage of air and moisture, and greatly deteriorates the herbage. It is therefore advisable to avoid deflocculation or puddling by every possible means. On the other hand, flocculation of clay brings about an aggregation of its particles. This gives it more of the texture of a coarse-grained mass with all the advantages of larger interspaces for the passage of air and the percolation of water. The clay-land farmer can best improve the condition of his soil by the liberal use of lime and of farmyard manure, the periodical ploughing-in of a grass sward, and by ploughing early in the season so that the furrows are exposed to frost and weathering before an attempt is made to prepare a tilth; and, of course, it is of the utmost importance never to work such land until it has attained a certain degree of dryness. When clays are caused to expand by the temperature dropping to near freezing-point, the lateral pressure is liable to cause the extrusion of stones, roots, etc.

On the whole, clay soils are rich, and when well handled in suitable seasons they are capable of growing splendid crops; but they tend to dry very slowly and are difficult to drain, their coldness and wetness make them late, and their tenacity causes them to be difficult and costly to work. Moderately heavy soils are highly drought-resistant, but very heavy clays, especially when under grass, are less satisfactory from this point of view. A good deal of the winter rain may run off, and in time of drought the clay cracks, with serious damage to the plant roots. Moreover, once the soil has cracked subsequent rain runs down the fissures, and the mass of the top soil may remain dry for the rest of the season. Plants growing on clay tend to develop less fibrous and fewer roots than plants on light soil. Owing to their coldness and lack of air, clay soils tend to accumulate organic matter, and dressings of farmyard manure are very lasting. Most clays have very large natural reserves of potash but may be poor in phosphates and sometimes in lime. The physical qualities of clays are obviously modified when they contain a good proportion of gravel and stones, which lower the specific heat, improve drainage, and make the soil earlier and easier to work. Because of high labour costs, a great deal of our heavy land which was largely used for grain-growing up till the seventies of last century was converted to grass when grain prices fell and wages rose. Considerable areas have, however, been brought back into cultivation since 1939. The introduction of leys makes them much more tractable and productive. Typical clay-land crops are wheat, mangolds, cabbages, and beans.

Clay loams are intermediate in type between heavy clays and loamy soils.

Loams contain from 8 to 15 per cent. of clay and may be considered the best all-round type of agricultural soil, capable of growing any crop. Their texture is such that they have most of the advantages of both clays and sands yet none of their serious disadvantages. Owing to their high content of sand they are free working, well aerated, easily drained, and respond well to organic manures which soon decompose and become available for plant food. Their clay fraction, however, gives them a sufficiently fine texture to enable them to withstand considerable periods of drought. Like clays, loams cannot be worked when they are in a wet condition, but as they drain freely and warm up early in spring they are in fit condition for tillage over much longer periods.

Sandy loams share the characteristics of the loams and the sands. They are not naturally rich but are very early, easily worked, easily drained, and respond to heavy dressings of manure. They are therefore greatly favoured by market gardeners who can afford to manure heavily and to water if necessary.

Sandy soils contain only about 5 per cent. of clay and are therefore composed of relatively large particles which make them open in texture and easily drained, but at the same time cause them to dry out rapidly during periods of drought. As sandy soils are so largely made up of practically indestructible fragments of mineral matter they are extremely poor in plant foodstuffs and are often short of potash, phosphates, and lime; yet they promote such extensive root development that the response of crops to phosphatic fertilizers is often less than would be expected from their analysis. Under certain conditions sands accumulate organic matter, because in the absence of lime the decomposition of plant debris cannot proceed, and a surface layer of raw humus may be formed; but under normal field conditions, where liming has taken place, they are so well aerated that dung and plant remains decompose very rapidly. Sands are therefore generally called "hungry" soils. Because of their low water-holding powers and their consequently low specific heat they warm up rapidly in spring and enable early sowing to take place. The dry conditions also cause crops to come quickly to maturity, and if the yields are rather small the quality of the produce is usually good. The risk of puddling these soils is so inconsiderable that they may be cultivated during all seasons; hence they are very suitable for forms of continuous cropping and market gardening. For this purpose they of course require liberal manuring. Sandy soils are useless when they overlie hard-pan, rock, or gravel, for these subsoils make the water conditions impossible for agriculture; they are best when they rest on a subsoil of good water-holding capacity and when they receive a liberal and well-distributed rainfall. Where rainfall is adequate it is possible to bring sands into cultivation by marling, or by claying and liming, combined with heavy manuring, but this will be profitable only where supplies of clay or marl are available locally. By the use of organic fertilizers such as dung, by green manuring, and by consolidating with heavy rollers and the treading of sheep, the texture and water-retaining power of sandy soils are greatly improved and their fertility is enhanced. Because

of their lack of tenacity and the ease with which implements work in them, sands are known as " light " soils. When they contain a high proportion of gravel or stones they are correspondingly less fertile and more liable to " burn " in dry weather. The crops best suited to light and sandy land are rye, barley, turnips, carrots, potatoes, and lucerne.

Peaty soils are of different kinds in this country, their worth depending to a great extent on the proportions of organic and mineral matter in their composition. Taking the extreme case of a deposit of peat or a peat-bog, one finds that the soil and subsoil are composed of an accumulation of plant debris, such accumulation only taking place under waterlogged conditions where the absence of lime and air prevents normal decomposition. The plant remains are not, however, absolutely preserved, but are converted into true peat by certain organisms which work in the absence of air. Such soils are practically pure organic matter, and compared to other soils are very nitrogenous. But so long as a bog remains in its natural condition it is useless for agriculture, and it is only by the expenditure of a large amount of capital that it can be made suitable for cropping. In the reclamation of a peat-bog the first step is to dig large open drains to carry off the water and to allow the land to settle, aerate, and dry ; thereafter it may be made fertile by liberal dressings of sand or clay—which may be obtained in excavating the drainage channels—and of lime, phosphate, and potash. Some areas have been successfully reclaimed by the application of city refuse. This means that to get a bog into cropping condition the soil has, in effect, to be manufactured, and only a high level of agricultural prices can make this economic.

Another kind of peaty or black-mould soil is found in parts of the Fen country, where it was formed in marshy river estuaries by a certain amount of silt and the debris of reeds and estuarine vegetation. Originally very light and liable to blow, some of the soil is still in this condition, but most was given cohesion by top-dressing with the clay that underlies a large part of the area. Although black fen soils consist largely of humus they contain a fair proportion of mineral matter including lime. As much of the fen land has been reclaimed by draining in recent times, the decomposition of the organic fraction, though proceeding actively, is still far from complete, and the soil is still enormously rich in organic matter and nitrogen. Black fen soils have a friable, dry,

and sooty appearance and texture; they respond well to dressings of superphosphate, but for many years after their reclamation may be injured rather than fertilized by applications of dung and nitrogenous compounds. Even old fens give low responses to dung. Fen-land crops are heavy but not of the highest quality.

As mentioned above, organic matter may accumulate on sands because of the shortage of lime. Even on heavy land plant debris may tend to gather. Many old grasslands have matted turves many inches in thickness composed of dead but only slightly decayed plant remains. The reason for this accumulation of "mat" is the absence of the normal bacterial flora and of earthworms. Even if ploughed under, the mat, unless the acidity is neutralised, decays very slowly and the land remains infertile.

Suitable crops for acid, peaty soils are oats, rye, and potatoes. After liming and fertilization a wide variety of crops can be successfully grown, including sugar-beet, celery, and mustard.

Calcareous soils contain from 5 to 50 per cent. of carbonate of lime. Soils of this type, as one might expect, are most common on the chalk and limestone formations where they are formed *in situ* by the action of weathering; but calcareous clays, or marls, are common as subsoils in many parts. As lime is gradually removed by percolating water, it follows that in course of time a change to an ordinary mineral soil takes place. For this reason it is possible to have soil overlying chalk yet in need of liming.

Chalky soils, in winter, become soft and sticky and some types "puff up" under the influence of frost, so that autumn-sown corn is liable to lose its root-hold. If their clay content is considerable, as it commonly is, they bake into quite hard clods, which, however, crumble very quickly on re-wetting. In general they produce good crops of barley, spring wheat, clover, lucerne, and sainfoin, but require "building up" for winter wheat. They are ill suited to potatoes and most vegetable crops. Some have an exceptional power of "fixing" potash, in which case "combine" drills (see p. 111) must be used.

CHAPTER II

PLANT LIFE AND SOIL FERTILITY

MANY widely different types of plants are cultivated. Bacteria are important in dairy manufacture; yeasts are used in the fermentation industries and in baking; many fungi, notably the common mushroom, are grown for food; and coniferous species produce a large proportion of the world's timber. The farmer's crops, however, all belong to the class of flowering plants or angiosperms.

Apart from four exceptional groups, flowering plants obtain their needs of minerals and of nitrogen from simple salts in watery solution, *i.e.* in the form of ions of calcium, potassium, ammonium, sulphate, phosphate, nitrate, etc. They synthesize carbohydrate, which is the primary organic compound, from carbon dioxide, mostly obtained from the atmosphere, and water, taken up mainly by the roots. The source of energy for the process of carbon assimilation (photosynthesis) is sunlight.

One group of exceptions is parasitic plants such as dodder and broomrape; a second includes "insectivorous" species which secure their nitrogen compounds by trapping small animals; a third includes the heaths, azaleas, the beech, and several other trees which, through symbiosis with root fungi (mycorrhiza), are able to assimilate organic compounds, including compounds of nitrogen and phosphorus. The fourth, and much the most important group, includes most species of the order *Leguminosae*, which, by symbiosis with root-nodule bacteria, are able to assimilate free nitrogen and thus can be independent of a supply of nitrate or ammonium salts in the soil solution.

It would be out of place here to attempt to give even an outline of plant physiology, but it seems necessary to set out some of the facts that are important to the farmer.

Seed and Germination.—Ripe seeds are extremely resistant to both heat and cold. Some can survive the temperature of liquid hydrogen, and some can bear, for a period, that of boiling water. Moreover, their respiration rate is so low that many can

remain viable for many months in the absence of free oxygen. By contrast the vegetative parts of plants that are used for propagation—tubers, bulbs, etc.—are much more sensitive to heat and cold, and are dependent for survival upon a supply of free oxygen. Potato tubers, for example, are killed by a few degrees of frost, by heating to comparatively low temperatures, and, in perhaps two or three days, by submersion in oxygen-free water or in waterlogged soil.

The seeds of certain species will germinate even before they are " harvest ripe," *i.e.* before the stage at which they separate easily from the mother plant. Others remain dormant for periods of months or even years after they have been shed. In certain cases (of so-called " false " dormancy) the explanation is to be found in the fact that the seed-coat is impermeable to water. Most clovers produce a proportion of " hard " seeds which do not germinate until the seed-coat has been broken, either by decay or by artificial treatment. In other cases it may be that the seed-coat is impermeable to gases, so that, for so long as it remains intact, there will be a build-up, round the embryo, of carbon dioxide. In other cases (" true " or " physiological " dormancy) there is no known physical explanation. Dormancy is important in relation to the control of certain weeds and also to the treatment of malting barley.

Apart from dormancy in either of these senses, it is a familiar fact that seeds of different species germinate at different rates. Beet, mangolds, and carrots germinate slowly, cereals and crucifers very fast. Part of the explanation is that in the former group there is a coating of corky material that delays the absorption of water. In many cases germination can be speeded up by wetting the seed before sowing, though care is necessary; thus carrot seed will bear immersion in water for a day or two, whereas runner beans are " drowned " in a few hours. Mangold and beet seed may be wetted by sprinkling and turning over but should not be steeped.

Seed, for safe storage, must be kept dry. In many cases mould growth and heating will occur, especially in large bulks, if the moisture content exceeds about 16 to 18 per cent.

The environmental conditions for germination include a sufficiency of moisture, a sufficient concentration of oxygen, a relatively low concentration of carbon dioxide, and a temperature within a certain range. The optimum temperature is in most

cases about 65° to 75° F. Minimum temperatures (permitting only very slow germination) vary as between species; that for rye is about 36° F., for wheat, barley, and beet about 40° F., and for maize about 48° F. A high concentration of carbon dioxide, even if oxygen is present in normal amount, may slow down or even prevent germination. In the case of white mustard 3 or 4 per cent. of carbon dioxide is sufficient to prevent the process. This may largely explain the fact that weed seeds, buried more than a few inches deep in the soil, may lie dormant for many years; but it may also be that in certain cases the absence of light is the main explanation. Some species germinate best in total darkness, while others fail to germinate at all.

The length of time that seed will remain viable varies greatly from one species to another. Onion seed deteriorates so rapidly, even under good conditions of storage, that what is sown must be of the previous year's harvest. Wheat falls off, both in percentage germination and in germinative vigour, very slowly during the first three years and then much more rapidly. Seedsmen generally carry over, each year, quantities of root, clover, and grass seeds as an insurance against a poor harvest, and "yearling" seed of these plants gives quite satisfactory results. In the case of clover (because successive bad harvests occur rather frequently) two-year-old seed is often used, with quite good results. The seeds of many common weeds survive in the soil for long periods, in some cases for several decades.

Seedlings.—The seedling plant at first lives and grows by drawing upon the reserves of food material in the seed; not until its shoot has reached the light and has turned green can it begin to be independent. The point is important in relation to the depth at which seed should be sown. Small seeds, such as those of white clover, must be sown at small depth (generally less than an inch), otherwise their food reserves will be exhausted before the shoot can reach the surface. At the other extreme beans may be planted as deep as 4 to 6 in. In this connection it must be borne in mind that the material sown is not necessarily true seed. The "seed" of sugar beet or mangold is in fact a cluster containing usually two to three true seeds, which are very small, embedded in a piece of corky tissue.

Once germination has well begun the developing embryo requires a continuous supply of water. Wheat or turnip seed that has "chitted" will die if the soil dries out. Established

seedlings of most species will also die in the absence of sufficient moisture to enable them to continue growth. Those of the grasses, exceptionally, can survive in a shrivelled state for many months, recommencing growth after rain. Hence the farmer must sometimes wait until well into the autumn before he can decide whether or not he has secured a satisfactory establishment of grasses sown in spring.

Germinating seeds and young seedlings are exposed to many risks, for instance, insect or bird or rabbit damage, seed-borne or soil-borne disease, and inability to draw from the soil enough nutrients to keep them growing after they have exhausted their reserves. As might be expected, the elements required in largest amounts at the " weaning " stage are nitrogen and phosphate, which are major constituents of protoplasm. An adequate supply of these nutrients in the near vicinity of the seed is therefore important. Another factor is competition by other plants, including weeds, for light, moisture, and nutrients. It is easy to understand the loss of seedlings of slow-growing crops—for example, beet or carrots—exposed to the competition of fast-growing weeds ; in other cases there is no such simple explanation of the failure of seedlings to become established. Sometimes such failure is clearly a result of some form of competition ; for instance, meadow fescue establishes well when sown as the only grass in a mixture, or with timothy as a companion plant, but gives a very low establishment when sown with ryegrass. Even in the absence of such competition there are marked differences between species. In one experiment carried out at the Welsh Plant Breeding Station, under uniform conditions, the numbers of seedlings established, per hundred viable seeds sown, were :—

Italian ryegrass	52·1
Perennial ryegrass	44·1
Meadow foxtail	9·6
Smooth-stalked meadow grass	2·2

As might be expected, the proportion of casualties among seedlings varies with weather and soil conditions, and allowance must be made for this factor. For example, common seed-rates for wheat vary from about two bushels in early October to perhaps three and a half in December. But here again there are wide differences between species. The following experimental results

(expressed as numbers of established seedlings per hundred viable seeds sown) illustrate these differences :—

Date of Sowing	Perennial Ryegrass	Cocksfoot	Wild White Clover
March to May	78·07	48·8	55·1
May to August	65·0	48·4	42·1
August to September	80·9	49·1	13·0
September to October	69·9	18·9	2·7

The striking difference between the grasses and the clovers is no doubt related to the fact that grass seedlings are frost-hardy whereas clover seedlings are not.

Plant Development.—The development of the plant through its various growth phases (tillering or branching, flowering and ripening) is governed partly by temperature and moisture conditions but partly also by light, in particular by length of day. Plants of biennial habit and "winter annuals" (*e.g.* winter wheat) do not pass out of the vegetative phase until they have been subjected to cold. Thus winter wheat, sown in southern England in April, will usually fail to come into ear in the same season but may do so if there happens to be a May frost. Again, beet, mangolds, and carrots, which are normally biennial, may "bolt" or run to seed in their first year if they encounter frost at a particular stage of growth, but the propensity to bolt varies from strain to strain. The biennial habit of winter wheat or of sugar-beet can be broken down by chilling the sprouting seed, the process known as "vernalization."

In regard to their reactions to frost, plants are sometimes classified as "winter-hardy" and "frost-tender," but there is in fact no sharp line of differentiation. The winter varieties of rye are more frost-hardy than those of wheat, and these in turn are more frost-hardy than winter oats or wild oats, but any or all of these may be destroyed under specially severe conditions. Moreover, there is variation between different areas in this country. Many weeds—for example, charlock—which in this country are generally regarded as spring annuals and whose seedlings, established in autumn, are commonly winter-killed, may often survive the winter in Cornwall or South-west Wales.

Among plants that are more or less winter-hardy the effect of frost varies according to the conditions under which it occurs.

When the soil is frozen, and when therefore the roots cannot take up moisture, survival depends largely on the plant's ability to retain enough moisture. Hence drying winds may be the immediate cause of death. Again, resistance has been shown to vary with the sugar-content of the cell sap, so that plants are more resistant after a spell of bright weather than after a period of dull conditions.

A covering of snow provides protection from drying winds and at the same time admits a fair amount of light.

Sometimes winter killing is due to " throwing out " of the plants, caused by the expansion and contraction of the soil that occurs during spells of alternating frost and thaw. Some soils, especially those of high organic content, " heave " markedly.

It is a familiar fact that plants which have abundant space tend to branch freely while overcrowded plants do not. The tillering (branching from the base) of cereals is also controlled by light, so that a thin " plant " of wheat often fills out in spring. Flowering is largely controlled by length of day, or rather by length of night. Most of the plants of high latitudes are summer flowering, or " long day," *i.e.* they flower when the hours of darkness are reduced to four, six, or eight. In warm-temperate and sub-tropical regions the plants are mostly " short day," *i.e.* they flower in response to a period of ten or more hours of darkness. The habit of the plant can be broken by subjecting it to quite a short period of illumination in the middle of the night, or, conversely, by shading it in the morning or evening. Certain species—for example, such annual weeds as speedwell and chickweed—are " ever flowering," *i.e.* flowering is not controlled by the hours of darkness. The only considerable importance of these facts, in practice, is in connection with the transfer of plants from a given latitude to another that is rather widely different.

Plant Nutrients.—Apart from carbon, hydrogen and oxygen, which are obtained from air and water, the essential elements required by plants in substantial quantities are nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. The remaining essential elements, commonly known as " trace " elements, are iron, manganese, boron, copper, zinc, and molybdenum. A few others—sodium, silicon, chlorine, aluminium, and nickel—are " beneficial " to particular species. Sodium, for example, is highly beneficial to sugar-beet, mangolds, and fodder beet.

Nitrogen is a constituent of all proteins and of protoplasm. With the exceptions mentioned earlier (p. 36), nitrogen is mostly absorbed in the form of nitrate. Rice and other semi-aquatic plants take up their nitrogen mainly in the form of the ammonium ion, and most other species will readily absorb and assimilate the element in this form. But under well-aerated conditions the oxidation of ammonia to nitrate proceeds so rapidly in the soil that little ammonia is present, as such, at any given time. Soils under old grass, being much less well aerated than those in cultivation, often contain substantial amounts of nitrogen in ammonium form.

Soil humus acts as a reservoir of nitrogen, usually containing about one part of the element to ten parts of carbon. But nitrogen in organic form is not available to ordinary crop plants, and the release of nitrogen from humus, in the form of ammonia, is, under cool conditions, usually too slow to provide for the full requirements of crops. On the other hand, fresh nitrogen-rich organic matter, such as cake-fed dung or a clover-rich sod, may under summer temperatures release nitrogen too rapidly, with the consequence of over-luxuriant growth and, in the case of cereals, lodging of the plants.

The common symptoms of nitrogen deficiency are narrow leaves and an unhealthy pale-green colour. Excess of nitrogen is indicated by broad dark-green leaves, lush growth, and increased susceptibility to frost damage. These effects are most marked when an over-supply of nitrogen is accompanied by a deficiency of potash (see further pp. 85-94).

Phosphorus is a constituent of one group of proteins and of protoplasm. It is largely transferred to the seed in the process of ripening, so that grain or pulse has a high content while straw contains very little. Phosphate is a constituent of animal bone and of milk, so that all forms of agricultural production, excepting only the fattening of mature animals, result in a drain upon the stock of phosphate in the soil. The quantity of phosphate present in many soils would be sufficient to provide for the needs of great numbers of successive crops, but much of the total amount is in unavailable form and a large proportion of what is applied as fertilizer " reverts " to an insoluble condition. Phosphate deficiency is indicated by poor early growth, a dull bluish-green colour of foliage, poor seed formation, and late ripening. Laboratory tests provide useful information on the amount of available phosphate in soil (see p. 83).

Potassium is taken up in large quantity and plays an important rôle in relation to the efficiency of the leaf tissue in carbon assimilation. In general, sandy and peaty soils are relatively poor in potash while most clays are rich. But, as in the case of phosphate, the greater part of the soil stock is in unavailable forms. Soil analysis provides useful information on the content of available potash. As might be expected, the crops that yield large amounts of carbohydrate material—sugar-beet, mangolds, and potatoes—have the highest requirements. The drain of potash from the farm as a whole depends largely on the quantities of potatoes, sugar-beet, green vegetables, hay, and straw that are sold. Animal products contain almost none, and grains and seeds very little.

Calcium occurs largely in the leaf and stem and mostly remains there as the plant matures. The common legumes (except lupins) are particularly rich in the element. Actual calcium deficiency in crops is rare, though cases have occurred, particularly in potatoes growing in extremely acid soils. The principal use of lime is in the control of soil reaction (see p. 26). The calcium content and the calcium/phosphate ratio of grassland herbage are important in relation to animal nutrition.

Magnesium is a constituent of chlorophyll and also plays a part in connection with the movement of phosphate within the plant; hence the addition of magnesium to phosphate fertilizers may improve their efficiency. Magnesium deficiency is not uncommon and can be aggravated or induced by unbalanced fertilization, especially the over-use of potash and the under-use of dung. It can be conveniently prevented by the use of dolomitic (magnesian) lime in place of the usual liming materials. Most low-grade potash salts contain magnesium.

Sulphur is a constituent of certain amino acids, many proteins, and protoplasm. It is absorbed in the form of the sulphate ion. It would seem that up till the middle of last century a good many British soils were deficient in the element, for there are many authentic accounts of responses to applications of gypsum. Sulphur deficiency is known to occur in other countries, but the long-continued use in British agriculture of superphosphate and sulphate of ammonia has resulted in the build-up of large reserves in most of our soils.

Manganese is required by all plants, but some suffer much more than others from the degrees of deficiency that commonly

occur. Deficiency causes a pathological condition in the leaves known as "grey speck" in oats, "speckled yellows" in beet and mangolds, and "marsh spot" in peas. Deficiency is most likely to occur in soils rich in bases (*p*H over 6·5), especially where the content of organic matter is high. Many cases have been related to excessive applications of lime. Affected crops can be cured by spraying with a dilute solution of manganese sulphate.

Boron appears to be essential, in greater or less amount, to all plants. Deficiency shows up as "heart-rot" in sugar-beet, "brown-heart" or "raan" in swedes, and "browning" in cauliflower. As in the case of manganese the use of excessive dressings of lime renders the soil reserves of boron unavailable; another point is that cases are most frequent on land that has rarely received dung. Boron compounds are rather readily leached from the land, and hence sandy soils are most prone to deficiency. Affected crops can be quickly revived by spraying with borax. In some countries deficiency is so common that a small amount of borax is incorporated in fertilisers for the more susceptible crops.

Copper deficiency seems to occur very rarely except on newly reclaimed peats. In Holland the condition is known as "reclamation disease."

Zinc deficiency is of great importance in certain parts of the world, notably in parts of Australia and the United States. Until recently it was thought to be of no importance in Europe, but definite response to applications has occurred on certain marshland soils in Kent.

Molybdenum was first recognized as being of importance by Australian workers who discovered that its deficiency was the cause of widespread failures of clover, the primary symptom being the failure of the plants to form root nodules. In other species the function of the element is related to nitrate metabolism; plants supplied with nitrogen in the form of the ammonium ion do not seem to require molybdenum. The only clear case of deficiency disease in Britain, at the time of writing, was "whiptail" in cauliflowers.

The trace-element requirements of animals are different from those of plants. The only deficiency conditions common in Britain are of cobalt and copper.

Plant Growth Substances or Plant Hormones are akin in their

action to the internal secretions (hormones) of animals, *i.e.* they regulate metabolism and growth. At the time of their discovery it was thought that related materials, either produced artificially or extracted from urine, etc., might stimulate growth or increase the overall efficiency of the plant. In fact, all that growth substances do is to influence the direction of development; for instance, they induce the plant to throw more than the normal amount of energy into the production of roots. In practice, synthetically produced materials are used to stimulate the production of roots by plant cuttings, to induce tomatoes to "set" without fertilization, and to prevent the premature drop of fruits. Their most important use is as selective weed killers, which use is based upon the fact that, at any given level of concentration, they have greater or less effect in the way of disorganizing the metabolism of different species at different stages of growth (see pp. 161-162).

WATER REQUIREMENTS OF CROPS

As the plant passes out of the seedling stage and increases its leaf area, its water requirements rise progressively up till the time when the leaf system reaches its full expanse. At the same time, however, the root system develops and ranges ever more widely, so that the plant's capacity to withstand drought commonly increases.

The amount of water transpired, per ton of dry matter produced, varies from four or five hundred tons in the case of cereals to more than eight hundred tons for the grasses. Hence plants producing 3 tons of dry matter per acre may transpire anything from 1200 to 2500 tons of water, equivalent to 12 to 25 in. of rain. The south-eastern half of England is too dry, on average, to permit of full yields of the general run of farm crops, and yields can be increased substantially by irrigation.

Drought resistance depends partly on the efficiency of the leaf in controlling transpiration and partly on the range of the root system and the level of root activity. To some extent these things are characteristic of the particular species or variety—for instance, wheat is more drought-resistant than oats and sugar-beet than swedes; but soil conditions are of obvious importance—for instance, a shallow soil over rock or gravel will have a low total capacity for water, sloping land may fail to absorb all the rain

that falls, and sandy soils drain very freely, while heavy clays may be so poorly aerated that root activity is depressed. Moreover, the development of the root system is influenced by the supply of plant nutrients, especially of phosphate. The immediate effects of drought are to induce the closing of the stomata and, later, the wilting of the leaves. In some cases—for example, in certain grasses—the leaves respond by folding up. Prolonged drought sometimes results in shedding of leaves, sometimes in the dying back of parts of the blades, and, of course, in extreme cases the shrivelling up and premature death of the whole plant. Under dry conditions the vegetative parts of the plant are reduced more seriously than the seed or grain; for example, a cereal, when grown with ample moisture, will yield very much more straw but not much more grain than it will produce in a moderately dry season.

Soil Air.—As will be explained later, the biological processes by which some soil nutrients are made available depend upon an adequate supply of oxygen and are checked, even in the presence of free oxygen, by any considerable concentration of carbon dioxide. Moreover, the plant roots must be able to respire. Thus the rate of gaseous exchange between the soil and the atmosphere is important. Lack of aeration may be due to waterlogging or to too close a soil texture, but it may also result from the formation of a surface crust or "cap." This is very apt to occur, in cases where the crumb structure is unstable, when heavy rain is followed by drying winds. Root activity is impeded by concentrations of carbon dioxide in excess of about 1 per cent. Soil aeration is important in another respect, namely, because the decay of organic matter, in the absence of free oxygen, gives rise to poisonous substances, notably to sulphuretted hydrogen.

Soil Temperature.—Air temperature is, of course, important in relation to rate of growth. Plants native to cool-temperate areas generally grow best at about 80° F., while carbon assimilation generally ceases below 40° to 42° F.

In clear, sunny weather the upper layer of a bare soil rises to a temperature much above that of the air. Conversely, on clear nights there is often "ground frost," while the temperature, 2 or 3 ft. above ground, remains several degrees above freezing-point. A blanket of vegetation makes a marked difference to the temperature of the soil, keeping it cool by day and warm by night. As might be expected, too, bare soil warms up in

spring faster than does pasture land. The point is important, since, even under British climatic conditions, the temperature of the upper soil layer may become too high for full root activity. Horticulturists employ mulches of straw, etc., to minimize the variation as between day and night soil temperatures. Soil under closely grazed or closely mown herbage shows a relatively high amount of variation, and root action may be greatly restricted by overheating of the soil during hot, sunny weather. Species show different degrees of tolerance, ryegrass being particularly prone to a degree of " summer dormancy " that cannot be fully explained as due to drought.

SOIL ORGANISMS

It is possible to grow normal healthy plants in a sterile aerated solution of nutrient salts, and there is no reason to suppose that the nutritive value of the produce, for animal or man, is in any way inferior to that grown under ordinary conditions. Certain glass-house crops, including tomatoes and some flowers, are grown commercially in water culture, though in practice there is no need to keep the solution sterile. The method—if care is taken to maintain a suitable concentration of the various nutrients and to keep the solution well aerated—has certain advantages over soil culture; in particular, it avoids trouble with soil-borne diseases and pests.

The farmer, however, works with a material that is inhabited by great numbers of living organisms—earthworms, nematodes, insects and protozoa, green algæ, fungi and bacteria—some beneficial and others harmful, and he can control the situation only imperfectly, and by more or less indirect methods. It is therefore necessary to have some understanding of the complex population of the soil and of the biological processes that go on in it.

Earthworms constitute the major fraction, by weight, of the animal population of the soil. There are many species, some six or seven of which are common in British soils. Their food is organic matter, either fresh or partly decomposed, and all obtain a proportion of it by foraging on the surface. All species are intolerant of drought, and require a reasonably well-aerated soil. Hence shallow and sandy soils on the one hand, and heavy clays on the other, contain relatively small numbers. The population

also varies with the supply of organic matter, so that fertile soils, producing large crops that leave large residues, contain greater numbers than poor land. Again, earthworm populations are higher in grassland than under arable conditions. Most species, including all the larger ones, require a continuous supply of calcium for their digestive processes, and their absence from very acid soils (below about *p*H 4·5) is very striking. Earthworms perform the function of mixing organic matter with the soil, and thus prevent the formation of a layer of surface litter in forest, or of a " mat " of dead plant material on grassland, both of which are characteristic of acid conditions. Earthworms improve soil conditions by promoting aeration and drainage and the power of the soil to absorb rain or irrigation water.

Some species—indeed the majority of those found in Britain—leave their castings on the surface. These consist of an intimate mixture of soil particles and organic matter, well saturated with calcium, and thus constituting a top dressing of loamy material that has an excellent physical structure. The dead bodies of worms are quickly attacked by soil bacteria and yield up nitrogen and other nutrients in readily available form.

Despite all this there is no convincing evidence of any marked overall effect of earthworms on soil fertility as measured by crop yields. In any case, it is only under exceptional circumstances that the natural methods of dispersal fail to provide the nucleus of a worm population, which quickly builds up if conditions are suitable. Some farmers, in the process of reclaiming salt marsh, inoculate the land by scattering about pieces of turf from an old-established pasture, in the probably well-founded hope that worm activity promotes drainage.

Other Soil Animals.—Under tropical conditions termites (white ants) play the major rôle in the initial breakdown of organic matter. Under temperate conditions the groups (apart from earthworms) mainly concerned are millepedes, springtails, slugs, and nematodes (eelworms). The first three groups, however, attack living plants as well as dead material, and certain parasitic species of nematodes, such as the potato-root eelworm, are among the most destructive of crop pests.

Protozoa are present in all soils but, since counts are extremely difficult to make, there is no very accurate information on the conditions that affect their numbers. Most of the common types feed largely on bacteria, and since a high level of bacterial

activity is an important factor in soil fertility, it was formerly thought that protozoa were harmful. It has, however, been shown that certain forms of bacterial activity, especially nitrogen fixation, proceed faster in the presence than in the absence of protozoa. The beneficial effects of partial sterilization of soil were at one time thought to result from the destruction of protozoa, leading to an increase in numbers of bacteria and thus to a rise in the rate of production of ammonia and nitrate. This explanation, however, fails to account for the beneficial results of the process.

The Soil Flora.—Turning from animals to plants, *green algæ*, which are single-celled plants containing chlorophyll, are present in most soils in great numbers, and those living on the surface, and in the upper soil layer, carry on the process of photosynthesis and thus make some small contribution to the stock of organic matter. They also assist in binding the soil particles into crumbs and, under swamp conditions (*e.g.* in rice fields), help to reduce the carbon dioxide and maintain the oxygen-content of the soil water.

Actinomycetes, which are somewhat intermediate in their way of life between bacteria and fungi, consist of thin, thread-like, much-branched hyphæ which in some cases break up into spores. They contain no chlorophyll but can make use of a great variety of carbon compounds. A very few species are parasitic on plants or animals. They are most active under warm, dry, and well-aerated conditions. It is probable that they have a beneficial effect on soil structure.

Fungi, as is well known, include many parasitic forms which are responsible for the majority of plant diseases—rust, potato-blight, club root, and many more. Most, however, are saprophytic (living entirely on dead organic matter), while others can live either on dead material or on a living host. They depend upon a supply of free oxygen, but flourish over a very wide *p*H range. It is fungi rather than bacteria which are responsible for the breakdown of dead plant material under very acid conditions, and the product—*e.g.* under a pine forest or heath, or very acid grassland—is raw humus (mor). But in farm soils also fungi play a part in the breakdown of humus, producing materials that are more readily attacked by bacteria than are the remains of the higher plants.

Bacteria are by far the most numerous of soil organisms, the

numbers in many cases running to hundreds of millions per gram. None contain chlorophyll but some are able to obtain their requirements of energy from sources other than organic matter, for example, through the oxidation of ammonia or sulphur. They may be divided into *aerobic* and *anaerobic* forms; the second obtain their oxygen by breaking down oxygen compounds, for example, by reducing carbohydrate to methane. Some can make use of either free or combined oxygen. A majority can assimilate nitrogen only in the form of compounds but some few can utilize nitrogen itself. In general, they grow best in a near-neutral medium and are inactive under markedly acid conditions.

THE NITROGEN CYCLE

It has already been said that the intermediate products of the decay of organic matter, including the remains of the organisms that carry out the process, are of importance in relation to soil structure, and that the nature of these products varies according to conditions—the composition of the original material, the lime status of the soil, and the presence or absence of free oxygen. The main types of intermediate product are peat (waterlogged conditions), raw humus (acid conditions), and mild humus (aerobic and near-neutral conditions). It has also been said that humus acts as a reservoir of nitrogen, from which the simple compounds — ammonium and nitrate — that alone can be assimilated by most crop plants are released mainly through the activities of soil organisms.

Nitrification.—The process by which organic nitrogen is converted into nitrate occurs in three stages. The organisms which break down organic matter require some nitrogen for the build-up of their own protoplasms, any balance being released as ammonia. The proportion so released will depend upon the amount of protein, in relation to that of non-nitrogenous organic matter, that the original material contains. Pure protein supplies about five times as much nitrogen as the organisms require, so that four-fifths will appear as ammonia. At the other extreme, material that is mainly carbohydrate (*e.g.* straw) releases no nitrogen at all, and indeed requires for its breakdown an additional supply of nitrogenous material such as urine or an ammonium salt.

The second stage is the oxidation of the ammonium ion into nitrite; nitrate, the end product, is produced only by the further oxidation of nitrite. The conditions required for these latter processes include, of course, a plentiful supply of oxygen, but also adequate supplies of calcium and phosphate and of four trace elements (iron, manganese, zinc, and copper) in properly balanced proportions.

The ammonification of nitrogenous organic matter is brought about by a variety of organisms, whereas the oxidation of ammonia is carried out by particular species of bacteria—the first stage by *Nitrosomonas* and the second by *Nitrobacter*.

Nitrification can proceed only in soils that are moist as well as freely aerated and within a temperature range of about 39° to 105° F. with maximum activity at about 85° F. It should be noted that the germination of many seeds and the root activity of many plants can occur at temperatures below the minimum for nitrification; hence crops can suffer from nitrogen starvation in spring even if there is an abundance of nitrogen-rich organic matter in the soil; in such circumstances many show marked response to fertilizers containing nitrates.

Nitrites occur in soils in very small amounts because the second stage of oxidation can be much faster than the first, but the proportion of ammonium to nitrate, at any given time, varies with the degree of aeration of the soil. Arable land generally shows a large excess of nitrate, while in grassland soils ammonia nitrogen may be two or three times as high as nitrate.

Losses of Nitrogen.—The nitrogen status of a soil at any given time depends on the balance between past gains and losses. Apart from the physical removal of organic material by wind or water (erosion) the losses fall on the inorganic compounds.

Where there is an insufficient supply of free oxygen in the soil, by reason of waterlogging or a very close texture, many bacteria fall back upon oxygen compounds. It has been said earlier that, under such conditions, the reddish ferric compounds are reduced to greenish-coloured ferrous compounds, which change is due to the action of soil organisms, chiefly bacteria. Nitrates are another possible source, being reduced to nitrites, ammonia, or even to free nitrogen, the process being known as denitrification. This process, of course, necessitates the presence of relatively fresh organic matter as a source of energy. Another cause of loss is the volatilisation of ammonia which may, for instance,

occur in alkaline soils under warm conditions, in which circumstances the formation of ammonia takes place faster than the product can be oxidized to nitrate.

Secondly, nitrates are very easily leached, and the drainage water from land that is in a good state of fertility may contain as much as the equivalent of 1 cwt. per acre per annum of sulphate of ammonia. Other losses that occur are less easy to explain—for instance, under dry prairie conditions, where practically all the rain that falls is evaporated, it has been shown that the annual loss of nitrogen following the breaking up of a virgin sward may, over a period, be about three times as large as the amount removed in the crops.

Gains of Nitrogen.—Apart from the application of fertilizers, the most important agent in adding to the stock of soil nitrogen is the leguminous plant living in symbiosis with its appropriate strain of the nodule organism, *Rhizobium*. The legume produces the carbohydrate and the organism synthesizes the nitrogen compounds required by the partnership. The organisms in question can be cultivated in artificial media and can survive in the soil, in the absence of the legume partner, for periods of ten years or more; but they do not fix nitrogen except when living symbiotically.

The nodule organism has high requirements of calcium and most strains become inactive at soil reactions more acid than about *p*H 5. Exceptionally, lupins nodulate freely, and nitrogen-fixation proceeds normally, in soil that is quite acid. A high phosphate status seems to be required, under all circumstances, for full activity.

The organism exists in many distinguishable strains, each one being more or less effective in combination with several different genera of legumes, but a particular strain is fully efficient only when associated with a particular genus or a group of closely related genera. The four most important types, under British conditions, are respectively adapted to the following groups of crop plants :—

1. Lucernes and Medics (*Medicago* and *Melilotus*).
2. True Clovers (*Trifolium*).
3. Peas, Field Beans, Vetches, and Vetchlings (*Pisum*, *Vicia*, *Lathyrus*).
4. Lupins and Seradella (*Lupinus* and *Ornithopus*).

This adaptation is not always clear-cut, *i.e.* there are many generalized strains that are more or less effective over a wide range of legume genera. A further complication is that some strains of organisms, while they freely invade the roots of particular species and produce nodules of normal appearance, fail to provide the plant with any substantial amount of nitrogen, *i.e.* they behave as parasites rather than as partners. Moreover, once a particular plant is invaded by an ineffective strain it is immunized against other types which would be effective as nitrogen collectors. Inefficient strains of the clover group are common in the soils of certain upland areas of this country, so that clovers grow weakly and fail to build up nitrogen in the sward.

Like many other groups of bacteria, the nodule organism is subject to attack by several strains of bacteriophage, each phage being restricted to its particular group of bacteria. The presence of such phages has been supposed to account for clover or lucerne "sickness" of particular soils, but this has not been proved.

Annual legumes are ordinarily invaded, and form nodules, within a few weeks of the germination of their seeds. In the case of perennial plants infection takes place throughout the growing season, but the nodules are annual growths, being shed in autumn and renewed, by fresh infections, in the following spring. A point of some importance is that infection of the roots is inhibited in a soil with a high concentration of available nitrogen, *i.e.* nitrate or ammonium ions. Hence dressings of nitrogen, intended to give the legume seedlings a quick start, may do more harm than good.

Under certain conditions leguminous plants excrete nitrogen —presumably surplus supplies—from their roots and may thus directly feed companion plants such as grasses. But it seems that the amounts of nitrogen are ordinarily small. In the main the companion plant benefits through the decomposition, in the soil or on its surface, of the residues of the legume—leaves, roots, and the annual crop of nodules. These residues, being highly nitrogenous, yield up available nitrogen rapidly; indeed, a very clovery sward may yield so much in the year after ploughing that the first crop grows too luxuriantly. A balanced grass-and-clover sward decomposes more slowly and has a longer-lasting effect.

Again, a mixture of legumes and non-legumes commonly

yields a larger total crop than a pure legume. The following results of a Rothamsted experiment illustrate the point:—

	Yields per Acre (Pounds)	
	Total Dry Matter	Total Nitrogen
Oats alone . .	4800	55·0
Oats and vetches .	5480	100·2
Vetches alone .	3200	98·0

Another point of importance is that the various legume species add widely different amounts to the soil's stock of nitrogen, the herbage species such as clover and lucerne being generally much more efficient than the pulses. Thus in a Cornell (U.S.) experiment various species were grown in a two-year rotation with cereals, with the following among other results:—

	Nitrogen Harvested (Lb. per Acre)		Gain or Loss of Soil N per Rotation	Yield of Cereal (Cwt. per Acre)
	In Legume	In following Cereal		
Lucerne .	299	66	+122	23·2
Red clover .	125	51	+115	19·4
Field beans .	103	25	− 20	10·6

The annual increment of soil nitrogen effected by clovers and lucerne has been estimated in a number of experiments and figures of the order of 100 to 300 lb. nitrogen—equivalent to about 5 to 15 cwt. of sulphate of ammonia—have been recorded.

Free-living Nitrogen-fixing Organisms.—Apart from the symbiotic bacteria just discussed, a certain amount of nitrogen is fixed by free-living soil organisms. Thus the genus *Clostridium* is probably important in forest soils, since there is no other known means by which the nitrogen requirements of certain types of forest growth can be met, *i.e.* there are no leguminous shrubs or herbs in the undergrowth. In agricultural soils the several genera of *Azotobacter* are common, and it is an established fact that these can use and fix free nitrogen. The species found in

Britain occur only in near-neutral or alkaline soils (*p*H above 6). Some blue-green algæ and several other groups of bacteria can also grow in the absence of nitrogen compounds. The chemistry of the process is not understood but it is known that neither the blue-green algæ nor *Azotobacter* will fix nitrogen in the presence of nitrates or ammonia. Moreover, *Azotobacter* requires for its activity a source of energy in the form of sugar and other simple organic compounds; cellulose and starch cannot be used directly but the organism can live symbiotically with other species that can break down the cellulose and other carbohydrates of straw.

In general there is very little evidence that *Azotobacter* and other free-living organisms are of practical importance under the conditions that prevail in British farm practice, and there is nothing approaching proof that soil inoculation, under British conditions, results in any benefit.

Soil Erosion and Soil Conservation.—Under conditions such as prevail in Britain—relatively low evaporation and moderate, well-distributed rainfall—the natural processes of erosion are relatively slow. It is true that cultivated soil tends to move slowly down steep slopes, and that occasional rainstorms may result in local damage by surface run-off, but in most cases steep slopes are difficult of cultivation and are therefore left in pasture or rough grazing or forest. It is true that our lightest sandy soils, and also certain types of black fen, "blow" when high winds occur during dry spring weather, causing ditches to be filled up and seedling plants to be uprooted. Again, however, the damage is commonly only temporary; but in many parts of the world erosion has assumed disastrous proportions.

Wind erosion is the less serious problem of the two. The most successful of control measures has been the replacement of the mould-board plough by a heavy disc which does not completely bury stubble and trash but merely anchors the material in the soil so that it acts as an efficient wind-break.

The control of soil-washing is based on the principle of inducing the rain to penetrate the soil rather than to run off the surface. This is accomplished, in the case of arable land, by a combination of measures. The first group is designed to maintain a good crumb structure, to the end that the soil will be kept in highly absorbent condition. This object is attained by ploughing in a grass sward at suitable intervals, or by green manuring. The second group aims at keeping the surface covered with living

or dead vegetation during the greater part of the year, and especially during the season of heavy rains, growing vegetation protecting the surface from rain splash and forming an efficient brake on the surface movement of water. Thirdly, there are measures designed to intercept the run-off; they include contour cropping (whereby the lines of row crops follow the contours) and broad-base terracing (a ridge-and-furrow layout again follows the contours). Where such measures are likely to be inadequate the land is best left in pasture or planted to forest.

In areas with marked dry and wet seasons even grasslands may suffer severely. On the one hand, over-grazing during the dry season reduces the plant cover to a point where it no longer acts as an effective brake on surface water so that soil is removed from slopes and deposited on flat areas below. On the other, the daily movement of stock from areas where there is grazable herbage to watering points, and back again, results in the complete destruction of the plants along the routes of travel, and hence the formation of dusty trackways, which rapidly develop into ravines as the loose soil is washed away by rain. The necessary measures of conservation may include a reduction in the head of stock, or alternatively the use of fertilizers to produce more keep; the conservation of fodder against the dry season, so as to avoid over-grazing; and the provision of water supplies at a number of widely separated points so that, by using these in rotation, the daily movement of the herds may be controlled and the formation of trackways thus avoided.

CHAPTER III

LAND RECLAMATION AND IMPROVEMENT

RECLAMATION

IN Britain the process of converting virgin land into farms has been going on for some four thousand years. In general the process was slow and piecemeal until about the middle of the eighteenth century because, until then, the rate of increase of population remained slow. Some coastal embankments date back to Roman times, and drainage works on a really vast scale were carried out, in the Fens, in the period of the Stuarts. The most active period of reclamation was the century from 1760 till 1860, during which time population was growing very rapidly and there was still no considerable supply of grain from the New Countries.

This, however, is not to say that the farm area has been static during the past ninety years. In fact, a good deal of land has been abandoned or allowed to revert to rough grazing during times of agricultural depression, and has had to be brought back into production in periods of emergency. Thus there was a decline in the farm area in the periods 1890-1910, and again between 1925 and 1939, while there were considerable reclamations in 1917-20 and from 1940 onwards.

The following brief notes indicate the principles to be observed in the reclamation of various types of land.

Tidal Marshes.—The reclamation of land that is much below mean sea-level necessitates major engineering works. It is essential to build massive sea walls and river banks, and to raise the drainage water from the reclaimed area by pumping. The greatest project of this kind which has so far been attempted is that which will eventually make available for farming the greater part of what was the bed of the Zuider Zee in Holland.

On the other hand, land that is under water only at high spring tides is relatively easy to reclaim. On parts of our coast, particularly round the Wash, silt is gradually being deposited by natural processes, and from time to time a new area reaches a level that makes embankment feasible. The deposition of silt can often be

speeded up by planting rice-grass (*Spartina Townsendii*) in the shallow tidal area, and by erecting groynes in the deeper water so as to check the rate of outflow of the tide. When the flats are considered to have reached the desired level an embankment is made as far out as practicable. Rice-grass is again useful for protecting the seaward side of the bank against erosion by the sea. Main drains are taken through the sea wall by means of large steel pipes, the outer ends of which are provided with sluices which open to release drainage water but are closed by the backward pressure of the sea at high tide. The soil, when first laid dry, is, of course, impregnated with salt, and may contain so high a proportion of sodium clay as to be very sticky, impervious, and intractable. The lighter silts are quickly leached, provide useful pastures very soon, and in five years or so can grow the full range of arable crops. Heavy land may be treated with gypsum to expel the salt. The maintenance of the sea wall and of the drainage system is costly, but the charges may be more than covered if the land is inherently fertile, as it usually is.

Restoration of Sea-flooded Land.—Land lying below high-tide level and protected by sea walls will, of course, be flooded if the banks give way. At rare intervals a combination of circumstances puts a very exceptional strain on the sea-banks. Thus in 1953 exceptionally strong northerly gales, coinciding with the period of the spring tides, caused an unprecedented tide, with very heavy seas, in the southern end of the North Sea, causing large inundations both in Holland and along the English east coast.

The problem of restoration after such inundation is more difficult than the initial reclamation of salt marsh by reason of the absence of the salt-tolerant flora. Arable crops are quickly killed by relatively low concentrations of salt; certain of the common grasses are more tolerant, but these also may be killed.

The first step towards restoration is to re-establish the drainage system, which will generally have been put out of action, in order to enable the leaching of the soil. But it is only during winter that any considerable amount of leaching takes place.

The major remaining difficulty results from the formation of sodium clay, which is extremely plastic and sticky when wet and which dries into large, hard clods which do not shatter either under the action of frost or after repeated wetting and drying. If a soil containing any considerable amount of sodium clay is

worked while in wet condition, its structure will be completely destroyed, so that rain-water will fail to percolate through it. The damage to soil structure is much greater under arable conditions (owing to the absence of a root network and the low humus content) than in grassland.

It is thus inadvisable to attempt cultivation in the early stages, and even later the farmer must be content with very shallow working, with harrows or discs, at times when the lower layers are dry. Ploughing, apart from damaging the structure, would aggravate the problem by bringing heavily impregnated soil to the top.

The reconstitution of calcium clay can be expedited by surface applications of gypsum, which is sufficiently soluble to be carried down in percolating rain-water. An ordinary winter's rain—say 12 to 15 in.—will commonly dissolve about a ton of gypsum per acre. Hence a usual procedure is to apply 2 tons per acre and repeat if necessary after an interval of two years.

It is desirable to establish plant growth as soon as possible, even if there is no prospect of immediate profit from the crop, the point being that the plants will remove a certain amount of salt, and by their root action will help to re-establish soil structure. Barley, all things considered, is the best choice among the arable crops. Beet and mangolds are indeed somewhat more salt-tolerant, but their harvesting can rarely be achieved without harm to the soil. Ryegrass and the fescues are the most suitable herbage plants.

Black Fen.—This type of soil has been produced by the decay of reeds and other marsh vegetation under the prevailing anaerobic conditions. The soil is mainly humus but is not necessarily acid, since typical fen vegetation occurs only where the flood waters contain considerable amounts of lime. Patches of acid peat are, however, found here and there interspersed with the non-acid fen. These areas must be limed and may require dressings of copper, manganese, and possibly other trace elements. Drainage presents peculiar difficulties because the soil shrinks and decays when the surplus water is removed and air is admitted. This shrinkage not only soon disturbs tile drains, rendering them quite useless, but the whole surface may ultimately fall below the level of any convenient outlet for a main drain. Thus a large part of the black fen area, which was originally drained by gravity, can now be kept dry only by pumping the drainage waters into embanked rivers.

Drainage alone, in the case of the black fen, may produce land of relatively low value, since the soil, when dry, is often a soot-like material that is very subject to drifting. Young seedlings may be blown out by the roots, and the wind-carried material frequently fills up the open ditches on which the drainage mostly depends. Fortunately a great deal of the English fen country has a substratum of clay at a depth of a few feet, and it is often necessary in any case (*i.e.* in order to get good drainage) to cut deep and wide ditches which run well down into the clay layer. It is thus often feasible to apply a top dressing of clay to the soil and so give it the necessary cohesion. Large areas of the black fen were treated in this way when the original reclamation was carried out, but in some cases, where the vegetable layer was deep, the labour cost was prohibitive. This fact accounts for the occurrence of patches of "blowing fen" interspersed through areas of much better land. The use of modern mechanical excavators and of crawler tractors may in some cases enable the work of claying to be done at an economic cost.

Peat Bog.—Where there is no flow of hard water into a marshy area it is obvious that very acid conditions will develop, and that a type of vegetation very different from that of the fen land will occur. In extreme cases this may consist largely of sphagnum and other mosses. Large areas of lowland peat bog, locally known as "mosses," occurred up till the nineteenth century in various of our western districts—*e.g.* Chat Moss in Lancashire and Solway Moss in Dumfriesshire.

There are at least three possible systems of treatment for such areas after the preliminary work of main drainage has been carried out. In Holland, where there were once large expanses of peat overlying glacial sandy loams, the plan was, and still is, to cut off the upper sod, to dig out the peat and sell it as fuel, etc., and to replace the turf on the mineral soil. The barges used for transporting the peat to towns are used to bring back loads of refuse, which is spread on the reclaimed land and ploughed in. Moderate dressings of lime, phosphate, and potash, with sometimes applications of other elements (manganese, magnesium, copper, boron) are then enough to produce tolerable soil conditions for such crops as potatoes, rye, and oats. Later on, with further applications of lime, a wider range of crops can be grown.

In north Germany, where large areas of sandy material are overlaid by two or three feet of peat, generally of a kind that

cannot be profitably worked for fuel, wide and deep trenches are dug, and the large amount of sand so obtained is spread over the undisturbed surface. The shallow mineral soil so obtained can be neutralized and fertilized much more cheaply than the peat substratum, which is later brought up in small instalments by progressively deeper ploughings.

In still other cases—*e.g.* those of the Lancashire mosses—the procedure was to use the peat itself as the basis of the soil, and to apply large quantities of ashes and other city refuse, with lime and bones, to provide the necessary stock of plant food. By these means, and by the gradual oxidation of the peat itself, a fertile soil was ultimately produced; but it must be remembered that the geographical situation of the Lancashire moss areas was specially favourable—*i.e.* the nearby towns were a convenient source of the large quantities of the refuse required, and also provided good markets for farm produce.

Sandy Heath.—Where the texture of the parent material of a soil is very sandy, an extreme degree of "podsolization" can occur even under comparatively low rainfall; this is because rain so easily percolates the soil. At first the lime and other bases are washed out, so that acid-tolerant plants become dominant, *e.g.* poor grasses, bracken, gorse, and heather. The relatively strong acids produced by the decay of such vegetation dissolve out the iron and aluminium oxides, but these are again precipitated in the lower horizon, in certain cases producing a "hard pan." Percolating water even carries down whatever fine particles (silt, fine sand, and clay) the parent material may have contained. Thus is produced the characteristic soil profile, consisting of a thin surface layer of very acid humus, a deeper layer of coarse, bleached sand, and a relatively heavy subsoil with or without an actual iron pan.

The destruction of the surface vegetation presents little difficulty since this is usually sparse and the surface soil is very loose and light. If an iron pan is present this must be broken up, and it is often the best plan to accomplish this by trench ploughing, using a heavy, single-furrow tractor plough. The partial reversal of the three soil layers is generally advantageous, since the heaviest material is thus brought to the top and the sour organic matter is put out of the way. Ironstone weathers down fairly rapidly when it is brought to the surface.

The next step is to neutralize the acidity, which of course may

be done by means of chalk, ground limestone, etc.; but the most successful reclamation has been achieved where there were supplies of marl at reasonable depth and within convenient reach of the farm. In the days of cheap labour marl was sometimes applied at rates of the order of a hundred or more cart-loads an acre, which quantity was sufficient not only to provide an ample reserve of lime, but also to increase very notably the water-holding capacity of the soil. In a few areas the practice of marling has continued even under relatively high wage levels, and it may be that new mechanical methods of accomplishing the work will make for its revival. In the great era of heath-land reclamation, when large areas in Norfolk, Suffolk, Nottingham, and other counties were dealt with, the only other major treatment applied was a heavy application of bones. The recipe, in Norfolk, was "deep ploughing, marl, and bones." In many cases, however, the land was grossly deficient in potash and, for lack of potash fertilizers, the cropping capacity remained low until the potash content had been raised by years of stock-feeding with large amounts of purchased feeding stuffs, and by feeding, on the farm, all the crop produce except cereal grains. Modern reclamation plans take account of possible shortages of trace elements in addition to the almost universal deficiency of potash.

A further point to note is that it takes some time for even a heavy dressing of chalk, marl, or other coarse material to become incorporated with the soil, so that it is best either to begin with acid-tolerant crops—lupins and rye being specially suitable—or else to apply a second small dressing of lime, along with the seed, by means of a "combine" drill. This ensures a supply of lime to the young seedlings, which might otherwise find themselves in pockets of acid soil. The first crops should be ploughed in as green manures, or folded with sheep, in order to build up a supply of mild humus. After a few years of careful and conservative farming, such land can grow useful crops of barley, roots, clover, sugar-beet, carrots, etc., and also lucerne leys.

Moorland.—There is no clear-cut distinction between this type and the last; in both cases we are dealing with a heavily leached and therefore very acid and strongly podzolized soil. But the main cause of the condition in the typical sandy heath is the coarse and open texture of the parent material, whereas in the moors of the northern and western uplands the cause is the low rate of evaporation in relation to the amount of rain that falls—

i.e. even where the original material has been of rather heavy texture there is excessive percolation. A further point of difference is that our typical moorlands occur in areas covered by glacial drift, where boulders may be so abundant as greatly to increase the cost of reclamation, or even make it prohibitive. Again, drainage is frequently necessary for moorland, and this also may add greatly to the expense. On the other hand it is unnecessary to use bulk materials, such as clay or marl, to improve the water-holding capacity of the soil. Finally there is the point that the reclaimed heath will be best used for arable cropping, whereas for moorland areas the long-ley system (*i.e.* a rotation including only occasional cultivated crops alternating with long periods under pasture) is commonly the most appropriate.

The usual sequence of operations is to burn off the natural herbage (heather, wiregrass, molinia grass, etc.), to remove visible boulders, and then to plough and cultivate, making use of the various safety devices that are available to avoid breakages. The disc harrow is useful in the preparation of a tilth. A dressing of one or two tons per acre of lime will generally be enough to neutralize the surface layer of soil so far as to enable useful plants to establish themselves. Moorland soils, however, have a marked capacity to fix phosphates in unavailable form, so that rather heavy dressings of mineral phosphate or basic slag must be applied. Half a ton of mineral phosphate or 15 cwt. of basic slag per acre are common amounts. Potash may or may not be required, but a small application of nitrogen fertilizer is essential to start off the first crop, which commonly consists of grass.

In general, land that carries a strong growth of bracken is a much more promising subject for reclamation than such as is under heather, bilberry, nardus, or molinia. Bracken generally infests deeper soils that are relatively rich in potash. Bracken land should be ploughed in June, disked repeatedly, and sown to rape. Either in the following spring, or after a further "pioneer" crop, the land is sown to ley, preferably without a nurse crop. If fronds of bracken continue to appear these should be destroyed, while still young, by a heavy roller.

It will be obvious that reclaimed moorland will tend to revert to its natural condition unless steps are taken to prevent this. The essential steps are periodic ploughings and applications of lime and phosphates.

Derelict Clay.—The wide areas of heavy clay in the Midland

counties of England, in Suffolk and Essex, and in the Weald of Kent and Sussex, carried a natural vegetation of deciduous trees —oak, ash, alder, willow, etc., according to the local drainage and other conditions. Large areas of the forest were cleared in early times, when more easily cultivated land was still neglected. The reason for this was that heavy soil maintained its cropping capacity, under the old three-field system, much better than light. Up till about 1875 wheat production on clay soil still remained profitable, but from that time onwards the clay lands, except in the driest areas, were increasingly laid down, or allowed to "tumble down," to grass.

Where the drainage system was well maintained, where phosphates were supplied and a good system of grassland management was observed, the pasture remained productive; but on much of the poorer land the cost of these measures was not covered by the returns, and deterioration set in. The state of a typical semi-derelict clay area is as follows. The surface is generally in ridge and furrow, originally laid out in order to provide surface drainage, and the land has been enclosed by hedge and ditch. The ditches, however, have become choked and often overgrown by the adjoining hedges, so that the escape of surface water is no longer possible. This has resulted in the invasion of the sward by water-tolerant plants such as rushes and tussock-grass, which commonly grow in bands along the furrows. The upper part of the ridges may still produce a tolerably good sward, unless invasion by hawthorn, wild rose, bramble, etc. (which is part of the process of "reversion"), has become widespread. A further point is that the ant population is usually high, and the surface may be closely dotted with ant-hills, a foot or more in height and two or three feet in diameter. If the soil has become highly acid there will be a surface "mat" of dead, undecayed herbage, but severe soil acidity and the resultant mat are by no means universal.

The first step in reclamation is to clear the ditches. This may often be done, at relatively small cost, by the use of a mechanical drag-line excavator or other power implement. The use of such a machine may, however, be impossible until hedge-cutting has been carried out. Exploration of the excavated ditch will often disclose the ends of tile drains, and these should be cleared and repaired. The next operation is to remove the thorn and scrub. Moderately small bushes may be most easily uprooted by a

tractor with attached ropes or chains—*e.g.* three men may wind their respective ropes round three separate thorn bushes or patches of scrub and the tractor may then pull up the whole simultaneously. Other devices of the bulldozer type, fixed in front of the tractor, may give good results with less man power. Larger trees may be uprooted by various types of winches. The scrub is later collected and burnt. Ant-hills, if not very numerous, can be cut up by hand labour, a broad-bladed mattock or adze being used. If numerous, they may be cut off by a special implement and afterwards chopped up by a disc harrow. In some cases a heavy disc harrow, used two or three times, will itself do all that is necessary.

If it appears that the land will still be wet, the possibility of mole drainage should be explored before the more expensive tile system is adopted.

Even if a system of under-drainage is installed the ridges should not be immediately levelled, because this will put all the former top soil into the furrow and leave barren subsoil exposed along what was the crown of the ridge. It is better to carry out the levelling process by stages, applying at each stage a double dressing of fertilizer along the lines of the old crowns. The ploughing of steeply ridged land by multi-furrow tractor ploughs is difficult, and a single-furrow plough is to be preferred. In some cases ploughing has been done at right angles to the ridges and the furrows retained, but a high ridge-and-furrow layout is a great obstacle to mechanised cultivation. A rather heavy dressing of phosphate is almost invariably necessary to the production of arable crops or a good pasture sward. The soil should be tested for lime and available potash before any decision is made in regard to applying these.

Downland.—Chalk down commonly carries a thin soil, but the underlying chalk is so porous that crops do not greatly suffer from drought. The typical herbage is grass, with scattered gorse, hawthorn, etc., but fairly dense scrub may occur. Extreme potash deficiency is common. The scrub may be pulled by tractor and draw-chains, swept into windrows and later burnt. It must be remembered that the soil may contain great numbers of seeds of shrubs, so that two or three years of arable cropping should precede re-seeding to grass. It is often necessary, because of the marked tendency of the soil to " fix " potash, to apply potassic superphosphate, with cereal seed, by means of the combine drill.

5

DRAINAGE

The purpose of drainage is to increase the productiveness of agricultural soils by removing the free water which, mainly by excluding air, inhibits the growth and activity of plant roots. The need of drainage in any particular soil is exhibited by a wet and spongy surface, by the presence of rushes, sedges, tussock-grass, and other inferior herbage, by the stunted and sickly appearance of growing crops, which may be drowned out altogether in the hollows, and by the presence of pools of water and of characteristic dark-coloured, damp patches on cultivated fields. Wet land may be unable to bear the weight of tractors or stand the carting of roots in winter, and it cannot be stocked for fear of lasting damage to the soil texture. The colour of the subsoil tends to be grey, blue, or green instead of red, yellow, or brown as in soil that is satisfactorily aerated. As noted in the description of gley soils (p. 10) the zone of fluctuating water table is marked by mottled coloration. Even where the surface shows no sign of wetness a high water table may create conditions that are little better than complete waterlogging.

The improvements brought about by drainage are manifold :—

(1) The soils are more easily and sooner worked. Undrained soils have a high specific heat, are slow to warm up in the spring and, owing to the risk of puddling, cannot be subjected to the acts of tillage until excess water has been removed by evaporation. The improved mechanical condition, higher temperature, and earliness induced by drainage allow of a longer growing season and earlier ripening. As seed-time and harvest are earlier, arable crops may be grown instead of grass, and fallowing may be superseded by green cropping. It must be understood, however, that drainage cannot lower the water-content below the inherent field capacity of the soil and that, in the case of heavy soils, this is far above the limit at which tillage can be undertaken. The result is that clays lie wet in winter even if there is little rain and become fit to till only after exposure to drying winds.

(2) When the water is carried away from the surface layers of the soil, air enters the pore spaces and plant roots extend downwards. Thus the weathering of a fresh horizon of mineral matter is induced, the crops are able to absorb food from a greater volume of soil, and the produce is improved as regards both quantity and quality: When pasture is drained the poor herbage gradually

disappears and is replaced by strong-growing natural grasses of superior nutritive value and by white clover. Even in very dry summers drained land gives better results than does undrained, because the plant roots are so much better developed.

(3) The beneficial action of micro-organisms is stimulated and there is consequently a more rapid liberation of plant food; lime and manures act better and more quickly. Certain parasites of live stock, such as liver-flukes and some parasitic worms, are reduced as surface dampness is removed.

(4) The percolation of water to the drains has a washing action on the soil particles, so that poisonous substances, which tend to accumulate under waterlogged conditions, are carried away, and, in the case of a soil rich in alkaline substances, the efflorescence of injurious salts is stopped.

Rivulets and streams form the natural drainage of any catchment area and must necessarily, in the course of time, remove all the rain-water that is not utilized by plants or evaporated. In order more rapidly to dispose of rain-water, and for other reasons such as the prevention of flooding, river courses may be modified and ditches added to the natural waterways. The construction, cleaning, and repair of these channels are generally the tasks of a public board or local authority.

Field drains may be open furrows or ditches or covered pipes. Open drains are less desirable as they occupy an area that might otherwise bear a crop, interfere with the movement of implements and with cultivation, harbour weeds and pests, and are costly in upkeep. They are, however, necessary where covered drains would be silted up by tidal or flood waters, or choked by tree roots, and also in deep peat or black fen soils, where tiles are liable to be displaced by the irregular shrinkage of the soil. They are also used in certain systems of irrigation and sewage farming. Ditches should be constructed so that they are sufficiently deep and capacious to drain the land they serve; the slope of their sides should be more gradual in friable than in strong soils so that they neither cave in nor slide, and their fall should be such that the water causes neither scouring nor silting. In practice, most systems of farm drainage have numerous covered field drains leading to one or two ditches, which in turn flow into a natural waterway.

Sheep or hill drains are narrow and shallow ditches made by digging out the soil to a depth of about a foot and heaping the excavated material and turf on the lower side; they are dug to

ameliorate marshy conditions where under-drainage would be either impossible or uneconomic. They can be made by means of a specially designed plough.

Principles of Drainage.—Except under arid conditions (where all the rain that falls is evaporated) there is a certain ground horizon below which water fills the pore space. The upper limit of this zone of saturation forms a plane that is known as the water table. When rain falls upon the ground its fate depends on a number of factors, such as the temperature and humidity of the air, the presence or absence of a crop, and the permeability and wetness of the soil. Usually some evaporates or is used by the vegetation, some is held by the soil, and some percolates downwards to the water table or drains away.

Rainfall in Britain is distributed fairly evenly throughout the year but there is far more evaporation in summer than in winter; moreover, plants transpire much water during the growing season. Thus in summer, soils tend to lose water and dry from the surface downwards. During winter, on the other hand, rainfall exceeds evaporation and water accumulates, first satisfying the field capacity of the soil and then causing the water table to rise. In normal seasons, and in all but our wettest areas, the only drains that run in summer are those which are supplied by springs; in autumn they will not run until the "field capacity" of the soil has been satisfied, *i.e.* until the soil contains more water than it can hold against the force of gravity; in winter they are likely to run almost continuously, or at any rate after every fall of rain. Light soils are freely permeable and have a low field capacity, so their drains are the first to run.

The permeability of soil depends on its relative proportions of clay and coarse particles. Pure or fairly pure clay, when puddled, is practically impermeable. At the other extreme, sands and gravels drain with great rapidity. Indeed, on much of our light land the farmer's main problem is to increase the water-holding capacity. Most soils are, of course, intermediate in type and even those rich in clay can be made permeable throughout the horizon of tillage by employing lime, organic manure, and cultivations to secure an aggregation of the fine soil particles and an improved crumb structure.

Where soil and subsoil are coarse in structure, water gravitates downwards, more or less vertically, from pore space to pore space; but when the subsoil is clay the only channels for downward

movement are those left by roots and worms or formed by cracking during periods of drought. In light land the water table rises after rain until it reaches the level of the drains and the water finds a way of escape, but in heavy land the drains are fed from above by way of the few open channels and the lines of weakness in the disturbed soil over the tiles.

The object of drainage is to offer a quick means of escape for water that is doing injury, and the depth and frequency of the drains are arranged to remove the water as effectively as possible yet at a minimum of cost. There is no profit in drainage unless its cost is more than met by the value of the improvement, and only land that is potentially fairly fertile is likely to bear the full cost of thorough tile drainage. State grants are, however, available to cover part of the cost.

The distance between the drains is determined by the texture of the soil. Clay soils offer so much resistance to the passage of water that they drain much more slowly than soils which are coarse in texture. Consequently, in order to get rid of surplus water reasonably quickly, it is necessary on clay soils to multiply the avenues of escape. In other words, the drains have to be placed at relatively close intervals. In the case of light soils, however, where tiles "draw" for a greater distance, it is obviously economical to space the drains more widely.

The depth of the drains has also to do with the rate of percolation. In heavy land, drains will not act with sufficient rapidity unless they are placed comparatively near the surface, say 2 or 2½ ft. Indeed, the water might fail to reach deep drains. On the other hand, drains may be placed at a greater depth in light soils; and because the deeper a drain is placed, provided that it works satisfactorily, the greater its "draw" and the fewer the number of tiles required for a given area, it is economical to place drains as deep as the texture of the soil will permit.

The following are the usual depths and intervals adopted for draining in this country:—

Soil	Depth in Feet	Interval in Feet
Clay	2 to 2½	12 to 20
Medium loam . .	2½ ,, 3	20 ,, 30
Sandy loam . .	3 ,, 4	30 ,, 40
Peaty	At least 3½	18 ,, 21

The drains in peaty soils may be laid 4 to 5 ft. deep to allow for settling and shrinkage of the upper layers, or may be placed even deeper if this would enable the tiles to rest upon a firm bed of mineral material.

The fall or gradient of the drains should be as much as conditions will allow, unless on really steep slopes where an oblique drain is more effective in intercepting water from springs, etc. In theory, farm drains should run satisfactorily if they have a fall of not less than 1 in 660, but, owing to the difficulty in ensuring perfect grading, it is considered that where possible the minimum in practice should be 1 in 250. The fall should be uniform, and on no account should a change be made from a steep to a less steep grade, because the check in the velocity of the running water will result in a deposition of silt which may choke the drain. If such a change is unavoidable a silt basin should be constructed at the junction of the two grades. A basin of this kind is a shallow well into which the water pours, is checked, and deposits much of its sediment, and from which, at a point slightly below the in-flow, it passes out into the drain with the lesser gradient. The basin is covered to prevent accidents, and the sediment is removed as often as is necessary. A large sewer tile, perforated for the affluent and effluent drains, placed vertically in the ground and covered by a stone slab, forms a cheap basin. In some cases, where there is no alternative, drains have been laid on the level across a field from one ditch to another.

Drain tiles should be circular in cross-section with regular ends that can be closely joined; they should be hard and should emit a clear ring when struck; they should be reasonably smooth on the inside and free from cracks that might reduce their strength.

In considering the size of drain tiles it is necessary to divide drains into two classes: (1) Lateral Field Drains; (2) Main and Sub-main Drains.

(1) In the practice of field drainage it has been found that drain tiles less than 2½ in. in internal diameter fail to give satisfactory service. Theoretically, a much smaller tile should suffice, but actually it is impossible to lay the tiles perfectly, and imperfect jointing and slight displacement so upset the working of small tiles that they choke up or fail to rid the soil of water. Indeed, many authorities maintain that it is inadvisable to use tiles less than 3 in. in diameter, because slight errors in the grade cause them to fill with sediment. But long drains that require 3 in. tiles

towards the outlets may be made with 2½-in. tiles at the tops. It has been pointed out that the interval between the drains does not depend on the carrying capacity of the tiles but on the texture of the soil alone. One may take it, then, that the diameter of the parallel drains should be not less than 2½ in. in a clay soil, where the intervals between the drains are least, or 3 in. in a sandy soil and, provided the laterals are not more than 250 yds. long and have at least a fall of 1 in 250, they will be capable of removing the superfluous water from the soil, wherever the drains are placed at standard intervals, under any British climatic conditions. It is of some importance to know that drains can be too short; in such cases, especially when there is but little fall, insufficient water may be carried to keep the channels clear.

Acres Drained by Tile Mains

Slope in Feet per 100 Ft.	Size of Tiles in Inches					
	4	5	6	8	10	12
0·2	4	9	14	30	55	90
0·3	6	12	18	37	67	111
0·4	7	14	21	44	79	127
0·5	8	15	23	50	89	142
0·6	9	16	25	54	98	156
0·7	10	17	27	58	106	169
0·8	10	18	29	62	113	181
0·9	11	19	31	65	120	191
1·0	11	20	33	68	126	200
2·0	16	28	46	97	176	280
3·0	18	34	55	118	212	350

(2) Mains and sub-mains are different. "Their size should be proportional to the rainfall, and the area and general slope of the land from which they receive drainage, without reference to the arrangement, number, or size of the laterals used in the system." Experiments have been made to ascertain the carrying capacity of pipe lines having different degrees of fall, and from the results it is possible to plan a drainage system capable of removing any quantity of water in a given time. While bigger drains will obviously be needed in wet districts than in dry, their actual size must also depend on the speed with which the water should be removed. If drains are made large enough to carry away the heaviest precipitation as fast as it falls, as in

draining a street, the cost will be very high. On the other hand, the removal of the water must be sufficiently expeditious to prevent the water table from rising and remaining in contact with plant roots for long enough to do harm. Actually the soil acts as a buffer between the rain and the drains, and usually allows the water to escape much more slowly than it is received, thus lessening the need for large tiles. In the end the drainage engineer, from his knowledge of the rainfall and other relevant factors, must plan for the removal of a given amount of rain in a given time, say for an inch or a suitable fraction thereof in a day. The figures on the previous page are taken from a diagram issued by the U.S. Department of Agriculture. They show the relationship between tiles, falls, and acreages where $\frac{1}{2}$ in. of rain has to be removed in 24 hours. This rate of removal should be satisfactory for somewhat wetter than average British conditions. In other districts where the removal of $\frac{3}{8}$ in. of rain in 24 hours would be satisfactory, the acres per drain may be increased by one-third; in the driest places the areas may be doubled. On the other hand, in the wettest parts, or where it is important to prevent any rise in the water table, the same drains may be used for three-quarters or even half the stated acreages. In practice it is, of course, frequently necessary to increase the size of the mains as, stage by stage, they are fed by field drains in their passage towards the outfall.

The Practice of Drainage.—The first thing to do in drainage practice is to decide on the system that is to be constructed and the location of the drains, and it is often helpful to dig a number of pits so as to observe the nature of the subsoil. A *natural system* is one where a line of tiles with a few branches is laid to drain a small area by following the natural outlets from higher to lower levels. The principal drain follows the chief depression and, where necessary, branches are run up the adjoining hollows. An *intercepting system* is one designed to catch water where it is seeping from a higher to a lower level and to remove it before it can do any harm to the bottom land. For example, a drain may be led across a slope to intercept water that is welling from a line of springs. A *parallel system* consists of a series of parallel field drains discharging into mains, which in turn carry the water away to some natural waterway. In undulating land the main drains usually follow the lowest levels, the sub-mains the lesser hollows, and the laterals are constructed either up or across the slopes according to the gradients. Fig. 1 illustrates simple

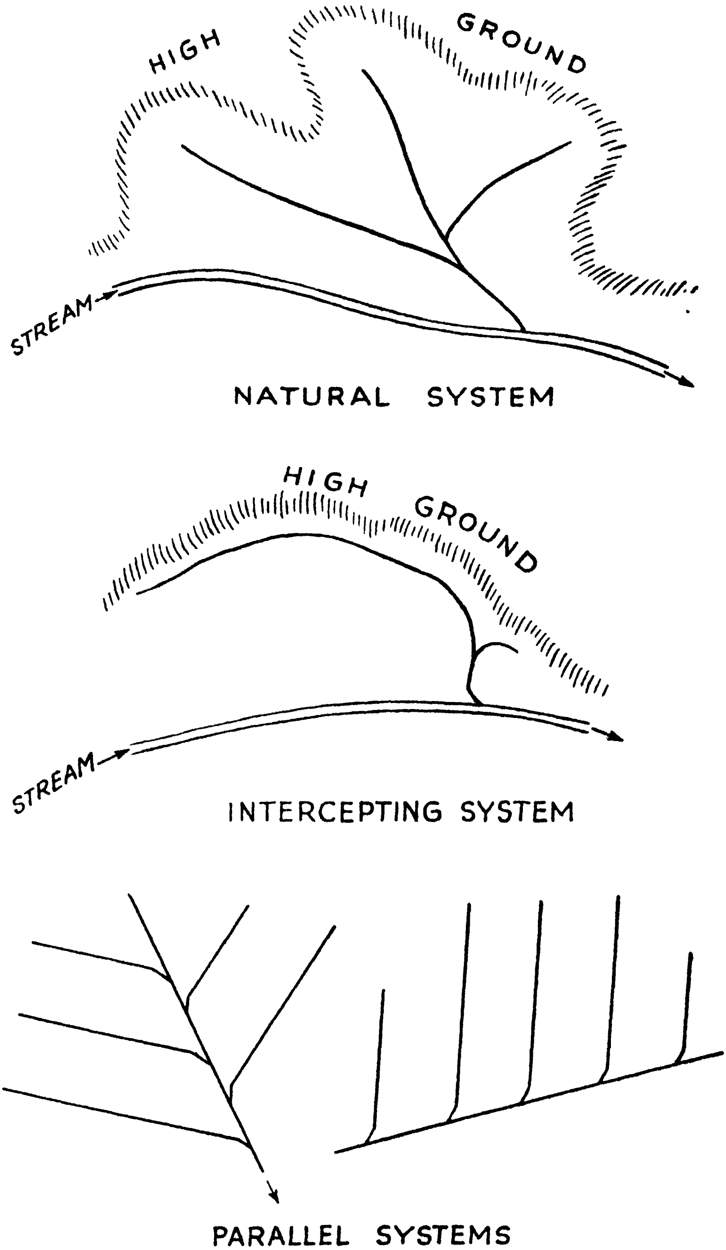


FIG. 1.—Arrangement of Drains

systems of drainage. In practice, however, the best layout of the tiles must be decided in the field, and this is likely to involve the adoption and modification of several systems. The line of the main drains should be kept 5 or 6 yds. from hedges or trees whose roots might block the tiles, and it is a good plan to keep clear of headlands where much carting is done. Great care must be taken in choosing an outlet for the main or leading drain. A clear drop into a ditch or other channel is best. Actually the difficulty of securing a good discharge point is a frequent obstacle to field drainage.

Having decided on the most suitable system, the next thing is to fix the exact position of the lines of drains. This may necessitate the use of levelling instruments. If the fall is very slight or obscure, most farmers would be well advised to call in the assistance of a surveyor, but if a good fall is assured and the system is not too elaborate, one should be able, by the occasional use of rough levelling devices such as boning rods and spirit-levels, to carry out the whole of the work.[1]

When a field of uncertain slope is to be drained it should be divided into squares by driving pegs into the ground. A level survey should then be made and each peg marked with its own level. If the position and levels of the pegs are marked on an ordnance survey plan of the field, the slope will at once be apparent, and the location of the drains can be made accordingly. The next thing to do is to put in a series of pegs along the line of each drain to mark the gradient. For example, suppose a lateral is 10 chains long and the difference between its highest and lowest levels is 3 ft. 4 in., *i.e.* it has a fall of 4 in. per chain. A peg should be driven into the soil at the top of the slope so that it protrudes 2 ft. above the surface, and, using a level and staff, another peg is driven at every chain down the slope so that the top of each peg is 4 in. below the level of the previous peg. A line along the tops of the pegs will represent the gradient of the drain.

When the location of the drains has been fixed, the drain tiles should be carted on to the land and laid down in convenient rows. The number of linear yards of tiles per acre is got by dividing 4840 by the proposed interval in yards between the drains. A 10-yd. interval would give 484 yds. of tiles, and if each tile is 1 ft. long [2] the number required would be 1452. This number,

[1] For a full explanation of the use of levelling instruments, the reader is advised to consult one of the numerous textbooks on Surveying.

[2] Tiles are ordinarily made from 12 to 15 in. in length.

however, must be increased by an allowance for breakages, and sufficient tiles must also be obtained for the mains and sub-mains. On boggy land the tiles may have to be laid on wooden soles to prevent their displacement, and the depth may have to be 4 or 5 ft. to allow for subsequent shrinkage.

When the drains are to be excavated by hand a cord is stretched on the ground to mark the true line of the trench along which the drainer works with his shovels and ditching spades. The top of the excavation need not be more than 12 to 14 in. wide, and the trench is narrowed to the breadth of the tile at the bottom. Considerable economy may be effected by ploughing out the top layers of the soil, or, better still, by using a mechanical excavator to remove all the material down to the required depth.

Drainage machines differ in construction. Some have bucket or endless chain dredgers, which, when propelled slowly over the ground, dig a trench to the required depth. Another is fitted with an enormous trenching plough and, when drawn by a tractor winch, can open a ditch 27 in. deep; a deeper trench can be made by fitting the machine with a deep excavating unit and going over the ground a second time.

When the trench is completed its bottom must be uniformly graded before the tiles are laid. To do this the drainer makes the bottom of his trench run parallel with the line along the tops of the gradient pegs. The prearranged depth at which the drain is to be placed $+2$ ft. (the height of the datum gradient peg) will be the depth of the bottom of the drain at any point along the line. Using an ˥-shaped rod to take sights along the tops of the pegs, the drainer carefully checks the depth of his trench, and, using his drain scoop, levels and grades the bottom until the fall is accurate and uniform. Whenever possible the flow of water should be tested before the tiles are laid.

The next part of the work is to lay the tiles, lowering them into position by means of a tile-hook and packing them carefully at the sides. The end of each lateral drain where it enters the main should be curved to form an angle of 30° to 45° with the larger drain, and should point in the direction of flow. Junction tiles undoubtedly give the most satisfactory and accurate jointing, but these are seldom available. Although many junctions have been made by laying the mains or sub-mains a tile's breadth below the laterals and packing the joint round with stones, it is better to lay the top of the lateral level with the top of the main and

to make a good junction by chipping the tiles. Where necessary, a little cement can be used to prevent silting at a rough junction.

Great care must be taken in the construction of the discharge point of the main into the natural waterway. Glazed tiles only should be used at this point, as ordinary porous tiles are soon broken to pieces by the action of frost. The last tile should be cemented into a brick or concrete foundation which cannot be undermined by running water, and the end should be covered by a grating to prevent the entrance of vermin.

The trenches may be filled in by means of a spade, a plough, or a special soil scraper, stiff clay being left out where possible.

Equipment is available for drawing a line of tiles into a previously made mole drain, and an elaborate machine is available to dig a trench and lay a line of tiles in the bottom in a single operation. Any irregularities in the laying of the tiles are corrected before the trench is filled in, which operation is carried out by a separate implement of the bulldozer type.

When the work has been completed, a survey of the drainage system should be drawn up and entered on the plan of the field. Such a plan will prove of immense value should it be necessary to trace a choked or displaced drain.

MOLE DRAINAGE

With the exception of permanence, mole drainage has practically all the advantages of ordinary tile drainage, and is far less costly; but it can only be practised on soils which are heavy in texture and free from stones or veins of sand or gravel, and on land with a smooth and regular surface where a good fall is assured; again, the life is short on arable land, especially where heavy implements are used. Under suitable conditions, in soils containing at least 45 per cent. clay and not more than 20 per cent. sand, the drains may last twelve years or more; on soils containing rather less clay and more sand their life will be proportionately shorter; on soils with less than 35 per cent. clay and more than 45 per cent. sand the job should not be attempted.

The drainage is performed by dragging a projectile-shaped iron " mole " fixed on the end of a strong knife-edged coulter through the soil at a depth varying from 15 to 30 in. The mole is

usually about 2½ to 3½ in. in diameter and its passage forms an underground tunnel which serves to remove superfluous water. The walls of the tunnel do not readily collapse and the passage is kept clear by the action of running water. Heavy soils, except for a few surface inches, become practically impermeable, and it has been shown that water reaches the moles almost entirely through the coulter slits.

The construction of mole ploughs varies considerably. The smaller implements, capable of making a 2¼-in. drain at a depth of 16 in., have frames rather like ordinary ploughs, guiding handles, and very long slades; they can be drawn by an average-sized farm tractor. The larger mole drainers have heavy frames mounted on wheels: when pulled by steam tackle of the winding-gear type, powerful track-laying tractors, or a tractor winch, they can be used to draw a 3½-in. mole at a depth of as much as 2½ ft.

Where shallow draining is being carried out, it is usual to run a mole every 3 yds., but when the depth is over 2 ft. the interval can be increased to 4 or 5 yds. In all cases where the land is laid up in ridges the drains run in the furrow bottoms. Where a very old system of tile drains is beginning to work unsatisfactorily, it is often preferable to proceed with mole drainage, at a lesser depth, than to carry out costly renovation.

Most mole ploughs can be drawn into the ground and to the proper depth like an ordinary plough, but they may also be started in a ditch or in holes that have been dug to receive the coulters; they work best if they are drawn uphill. When the mole drains run into a ditch their ends must be fitted with tiles that are properly secured. In most cases, however, mains will have to be laid to collect the water from the mole drains and lead it to a suitable outfall. These should be placed so that their tops are level with the bottoms of the mole channels: they may be 4-in. tiles, but nowadays it is not uncommon to make them by drawing two or three large-sized mole drains quite close together.

The mains and outfalls should be made first so that if the work is interrupted the system will function as far as it is completed. Heavy rain may do very serious damage to mole channels that are made before an outlet is provided. When in the act of draining a stone is encountered and the mole interrupted, the damaged section has to be excavated and laid with tiles.

IRRIGATION

The only important natural source of soil water is rain, the amounts supplied in the form of dew and by hygroscopic absorption being negligible. The two main causes of loss are firstly drainage, and secondly transpiration by growing plants. Losses by evaporation from the soil surface are, under British conditions, relatively small. The main factor affecting the rate of transpiration is sunshine. Wind is a minor factor, and in any case total air movement, per year, shows much less variation from one area to another than rainfall or sunshine. Low-rainfall areas are generally sunny, so that the water requirements of plants are higher in low-rainfall areas than elsewhere.

In arid regions, where the bulk of the plant's water requirements must be supplied artificially, and where evaporation from the soil surface is considerable, the quality of the irrigation water is important. If its content of soluble salts (especially those of sodium) is high, the accumulation of salt in the soil water may proceed rapidly. Many irrigation schemes have broken down because the soil has "salted up." This problem does not arise in Britain, where irrigation is used only to supplement the natural rainfall during the growing season and where the amounts required are ordinarily equivalent to only 2 or 3 in. of rain.

Even in our lowest rainfall areas the soil commonly reaches its field capacity in late autumn or early winter, and further additions, from rain or melted snow, escape after a longer or shorter interval by the drainage system. Field drains commonly continue to run until the spring. Thereafter, on cropped land, the loss of water by transpiration will usually exceed the amount supplied as rain, so that in all but the wettest areas the soil moisture-content falls below the field capacity. This loss, however, can go some way before it begins to restrict transpiration and plant growth, the amount of loss that can be tolerated, in soils of medium depth and texture, being equivalent to some 2 or 3 in. of rain. If the soil dries out still more, growth will be checked.

Obviously crops on a shallow or sandy or gravelly soil will suffer sooner and more severely than those on deep, heavy loams. Again, as is well known, crop species show varying powers of drought-resistance, the main factor being the balance between the depth and range of their root systems and the area of their leaf

surface; thus wheat and lucerne are more drought-resistant than oats and ryegrass. The date up to which active transpiration continues is another factor. Thus winter oats, because they cease to transpire actively by late June or early July, are less susceptible to drought damage than spring oats, which continue to need moisture for a month longer. Similarly kale, although deep-rooted, will suffer from a later summer drought that would not affect barley. In general, plants with a long growing season—sugar-beet, main-crop potatoes, most leafy vegetables, and especially grasses and clovers—require more water to enable full growth than cereals, late-sown turnips, etc.

Some progress has been made in mapping the country from the point of view of the expected response to irrigation of grass, together with such long-season leafy crops as sugar-beet, kale, brassicas, etc. In our driest and sunniest area—that bordering on the lower Thames estuary—substantial response to irrigation would be expected in nine summers out of every ten. In the south-eastern half of England (the line running from the Humber to South Devon) response would follow in five or more years out of ten.

It should be noted that irrigation may, under certain circumstances, achieve other objects than that of providing water. Apart from sewage irrigation, water from a chalk stream will neutralize soil acidity, and a supply fed from deep springs will, if applied in quantity, raise the temperature of the soil in late winter and thus promote early spring growth.

The earliest systems of irrigation in this country date back to the eighteenth century, when the commonest type was the water meadow, an area of valley-bottom land with a brook or stream as a source of supply. The area was laid out in a more or less irregular system of ridge and furrow, with supply channels running along the ridges and open drainage channels along the furrows. Water meadows, under suitable conditions, provided good early grazing and later good yields of hay. But the labour cost of upkeep is very high at present-day wage rates, and the layout prevents the use of modern hay-making machinery. Very few remain in operation.

In arid countries, until comparatively recent times, the choice of system was between flooding, "sub-surface" watering, and a method similar in principle to that used in water meadows. Flood irrigation is normal in the cultivation of "swamp" rice.

In the sub-surface system the water is led along shallow furrows, with a gentle and even slope running as nearly parallel as may be and at fairly close intervals. The slow-flowing water thus seeps into the lower zone of the soil and spreads laterally from either side of each strip. The system is specially suited to orchards. In recent times spray irrigation has become much more common, and it would seem that under British conditions, where relatively small applications suffice, the spray system is the most appropriate.

In spray irrigation, water under pressure from mains or from a pumped supply is fed into movable pipe lines supported a few feet above ground-level and distributing water over a belt several yards wide. The area is dealt with, strip by strip, by moving the outfit. Similar results can be obtained, with less labour in moving the tackle, by large automatic sprinklers which work on the same principle as those used for watering lawns or gardens. Since the area watered, in the absence of wind, is circular, it is well to mark out the land into a series of equilateral triangles, on account of the fact that a hexagon fits a circle much more closely than a square. For further information the reader is referred to works on horticulture, and particularly to *Technical Bulletin on Irrigation in Horticulture of the Ministry of Agriculture and Fisheries.*

Until recently it has been generally assumed that only market garden crops could repay the cost of irrigation, except perhaps on land immediately adjacent to rivers. It would now seem, however, that in the drier areas such arable crops as sugar-beet, fodder beet, kale, mangolds, and main-crop potatoes, as well as cabbage, brussels sprouts, and other market vegetables that are commonly grown on a farm scale, could be profitably irrigated. Moreover, irrigation could assist in maintaining a supply of material for grass-driers, and also of pasturage, during the mid-summer period when growth is often at a standstill.

WARPING

The practice of warping consists of flooding land with water containing a large load of rich sediment in order to form a new layer of soil, and the source of supply is generally a muddy tidal river. At high tide the lock gates are opened and the water is allowed to rush up channels and to flood the land quickly; the gates are closed and small sluices are opened which allow the

water to escape slowly. The check in the velocity of the water brought about in this way causes a deposition of sediment. Near tidal rivers this treatment can be carried out daily, though usually only the larger tides can be used, and in a few years 2 or 3 ft. of extraordinarily rich alluvium are laid down. After this the warping is stopped, and the original channels are retained for drainage purposes.

A large area of poor peaty land along the banks of the Humber and lower Trent was warped in the latter part of last century, and some has been done more recently. The area is now under intensive cultivation and produces very heavy crops of potatoes, wheat, etc. The term "warp land" is sometimes applied to natural as well as artificial alluvium.

CHAPTER IV

MANURES AND FERTILIZERS

THE fertilizing value of animal excrement, litter, and certain waste materials has been known from very early times. As recently as last century the only manures used, apart from dung and lime, were substances like bones, ashes, shoddy, and soot, but in modern times researches in chemistry and plant physiology have led to the introduction of a great many substances having manurial value, and the classification of fertilizers is now quite complex.

As mentioned before, plants must be able to obtain about a dozen elements if they are to exhibit healthy growth. Many of these elements are present in abundance in normal soils, and manuring concerns only the addition of those that are so deficient or so unavailable as to limit plant development. It has been found by trial that the only elements ordinarily required in large amounts to improve fertility are nitrogen, phosphorus, potassium, and calcium. Compounds of other elements—boron, manganese, zinc, copper, etc.—may properly be regarded as fertilizers, but these are required only in comparatively small areas of this country, and then only in small amounts. The science of manuring deals with the discovery of suitable compounds of these substances, their specific effects upon plant growth, and the most profitable methods of applying them.

Manures and fertilizers may be classified as "particular" and "general" according as they supply one only or several of the elements required by plants; or they may be divided into organic and inorganic fertilizers according to their origin. The bulkier organic materials are usually referred to as manures and the more concentrated as fertilizers. The term "artificials" should be avoided since certain fertilizers, like potash salts, nitrate of soda, and mineral phosphate, are naturally-occurring substances.

It has been said that a fertile soil should contain 0·5 per cent. lime, 0·2 per cent. nitrogen, 0·2 per cent. potash, and 0·15 per cent. phosphoric acid, but so many factors influence the productiveness of land that no hard-and-fast rule can be laid down. While the most suitable manuring for a particular case has usually

to be found by actual trial, soil analyses can nevertheless provide useful information.

Soil Testing.—Within recent years a number of methods have been worked out for estimating the "available" nutrients in soil and have been adopted in connection with the advisory services established at different centres throughout the country. In practice, the samples for examination are collected in the field by a member of the advisory staff and taken to the laboratory for examination in respect of their lime, phosphate, and potash status. The tests provide reasonably accurate information regarding the quantity of lime per acre necessary to secure any required alteration in the *p*H and less precise though still useful information in regard to the amounts of phosphate and potash that are rather loosely held by the soil—*e.g.* a soil can be categorized as very deficient, deficient, adequately supplied, or abundantly supplied with "available" potash.

The method of estimating the lime-requirement is given on page 28. The determination of "available," as distinct from total, phosphate and potash can be carried out by extracting the soil with weak citric or other acid, or even with water, and the results are interpreted by comparing them with the analyses of soils of known nutrient requirements.

Total phosphate contents of most soils range between 0·10 and 0·25 per cent., reckoned as P_2O_5. This is equivalent to a ton or two in an acre of top soil. The actual forms are apatite and related minerals, dicalcium phosphate, phosphates of iron and aluminium, and compounds of the phosphate radicle with the clay minerals and humus. A large proportion is always in forms that are not available to plants, and soil tests are designed to estimate approximately the amounts that are available. One method is to shake up a sample of soil with about ten times its weight of one per cent. solution of citric acid for twenty-four hours and estimate the phosphate (as P_2O_5) that has then gone into solution.

The following figures (in milligrams P_2O_5 per 100 gm. of soil) indicate the general status of the soil :—

Under 7	Very low.
8 to 11	Low.
12 to 15	Medium low.
16 to 20	Medium high.
Over 20	Very high.

Most crops will give marked responses to phosphatic fertilizers when the soil status is "low" or "very low," whereas response is exceptional when the status is "high" or "very high." But the figures must be interpreted differently for different soil types, and specific recommendations must be based not only upon the test results but on a knowledge of the behaviour of the particular type of soil in question.

Available potash may again be estimated by extracting with citric acid, though acetic acid or ammonium acetate is more generally used. The corresponding figures to those set out above (in milligrams K_2O per 100 gm. of soil) are :—

Under 3	Very low.
4 to 6	Low.
7 to 9	Medium low.
10 to 12	Medium.
12 to 18	Medium high.
Over 18	Very high.

The same reservation about the interpretation of the figures—*i.e.* the need for field experience with the type of soil in question—applies to the potash test. The same information can be secured by other means such as by growing rye seedlings under standardized conditions in small quantities of the soil and subsequently analysing the plants so that the figures may be compared with those from other seedlings grown under conditions of high fertility. With the aid of coloured illustrations, and with field experience, it is often possible to diagnose deficiencies of both major and "trace" nutrients in growing crops. In cases of doubt leaf analysis can be carried out.

NITROGEN FERTILIZERS

Under British conditions, and indeed in all areas where rainfall is high enough to cause any considerable amount of soil leaching, the supply of available soil nitrogen tends to be the commonest limiting factor in crop growth. It is, of course, always open to the farmer to ensure supplies by including frequent leguminous crops in his rotation, or by growing mixtures of legumes and non-leguminous plants, but it is often more profitable to use nitrogen fertilizers.

The effect of increasing supplies of nitrogen on plant growth is, up to a point, to stimulate the plant as a whole, to promote tillering, to cause an excessive development of stem and leaf, and to produce a rich dark green coloration of the foliage. An over-supply makes the tissues very soft and liable to attacks of pests and disease, reduces their resistance to frost, and so weakens cereal straw that the crop is easily laid. The liability to disease which may be brought about by excessive doses of nitrogen is believed to be mitigated by using potash fertilizers, which increase the efficiency of the leaf for carbon assimilation and maintain a better nitrogen-carbon balance in the plant as a whole. Heavy dressings of nitrogen may be better split if it seems that conditions are likely to cause leaching or over-luxuriant growth. Phosphates tend to promote root and seed development and thus produce a more balanced type of growth. The stimulation of vegetative growth by nitrogen retards ripening in cereals and may result in a difficult harvest. In a crop like turnips the large leaf development is of no value unless there is a corresponding growth of root, but in crops like cabbages and kale a luxuriant growth is an advantage provided the plants remain healthy. An over-abundant application of nitrogen may so increase the nitrogen-content of barley as to injure the malting quality of the grain ; it also tends to lower the sugar-content of beet and the dry-matter content of root crops.

If the supply of nitrogen for the plant is deficient, the effect is seen not in a reduction of the nitrogen in the tissues but in a general stunting of growth, for in such cases the amount of other nutrients taken from the soil and air depends on the quantity of nitrogen available. In addition, a yellowish- or reddish-green colour develops in the leaves and there may even be a certain amount of withering.

A point of some importance in the choice of nitrogen fertilizers is their respective effects on the lime-content of the soil, and there are other points such as rate of availability and liability to loss by leaching.

Sulphate of Ammonia.—In the combustion of naturally occurring carbonaceous compounds a considerable quantity of ammonia is produced from the nitrogenous matter which is always present, and in the manufacture of coal gas, the distillation of shale, and the heating of blast furnaces the ammonia is removed by passing the gases through sulphuric acid, sulphate of ammonia

being formed. A very large quantity is also made synthetically by fixing atmospheric nitrogen.

The fertilizer is sold with a guarantee to contain not less than 20·6 per cent. nitrogen, but it usually contains 21 per cent. It is in the form of small elongated crystals which may be white, greyish, or yellowish in colour. Formerly the salt contained a trace of free acid, which, being deliquescent, caused a certain amount of caking. Most supplies are now "neutral" and of excellent texture and keeping quality. Sulphate of ammonia must not be mixed with basic substances such as lime or basic slag, otherwise ammonia will be given off.

Although this fertilizer is soluble, the ammonium radicle is firmly retained by the soil and it is not until nitrification has taken place that the nitrogen is liable to be lost in the drainage. Sulphate of ammonia may therefore be applied to land some time before the crop is in a position to absorb it, for even under favourable circumstances it may be a week or more before nitrates are produced. In fact the fertilizer is often applied with the seed, or it may be given in small amounts to autumn-sown crops because, since cold weather reduces the speed of nitrification, the plants are able to absorb the nitrates as they are formed. As it is retained for some time near the surface of the soil it is more suitable than nitrate for shallow-rooted crops like turnips and barley.

The acid portion of sulphate of ammonia is washed to the drains in combination with calcium, and this results in loss of lime at the rate of about a hundredweight of calcium carbonate for every hundredweight of sulphate of ammonia applied. It should therefore be used with caution on soils that are poor in lime.

Sulphate of ammonia mixes well with superphosphate and potash salts and it is therefore very widely used in compound fertilizers.

Nitrate of Soda.—The world's great natural supply of nitrate of soda occurs in beds of soluble nitrates which owe their existence to the rainless climate of the district of Northern Chile in which they occur. The rock salts are mined and nitrate of soda is obtained in a fairly pure state by solution and recrystallization. A synthetic nitrate of soda has also been produced on a commercial scale.

The fertilizer was until recently sold with a guarantee of not less than 95 per cent. of sodium nitrate or 15·5 per cent. nitrogen, but a granulated form containing 16 per cent. nitrogen is now

generally available. The older form was that of rough crystals which varied somewhat in colour, but in the new material the white crystals are partly aggregated into granules and the texture is superior. The manure is deliquescent and, if stored in ordinary bags in a moist atmosphere, becomes damp and tends to cake or get lumpy. Supplies, however, are now usually marketed in treated bags which do much to protect the salt from dampness.

As nitrate of soda does not have to undergo any change before it can be assimilated, it is one of the quickest manures to act on the crop and will give results in weather too cold for the nitrification of sulphate of ammonia. It is soon washed down into the soil and so favours plants of a deep-rooting habit. It may to a small extent "scorch" a delicate crop by plasmolysing the tissues when it is first broadcast. It should therefore not be applied when the crop is wet with dew.

Nitrate of soda is not fixed by the soil and is very easily washed to the drains and lost; it should therefore never be applied in large quantities, nor should it be applied unless a growing crop is present to absorb it immediately. The sodium radical interacts with clay and humus in the soil and liberates a certain quantity of potash which becomes available for plant food; this gives it a particular value for potash-loving crops. Its continued use on heavy soil leads to the formation of a sodium clay which does not flocculate and which gives the soil a sticky texture. The sodium base has some effect in conserving lime, 1 ton of the fertilizer being in this respect equivalent to 5 cwt. of calcium carbonate.

Nitrate of Lime.—This is a synthetic nitrogen fertilizer prepared from the nitrogen of the air. In the manufacturing process atmospheric nitrogen is oxidized to nitric acid by the use of powerful electric arcs, the acid is neutralized by limestone, and the fertilizer is obtained from the solution by crystallization.

As nitrate of lime is completely soluble it can at once be taken up by the crop and is valuable as a top dressing. As it is in the form of a soluble calcium salt it is often used on soils that are poor in lime, and for certain crops under these conditions it may be expected to give better results than sulphate of ammonia. Its power of absorbing moisture from the air may be advantageous in allowing it to go into solution and penetrate the soil during periods of drought.

Nitrate of lime is not fixed by the soil and should be used only

as a dressing for growing crops. An application of 1 ton of the fertilizer has approximately the same influence in correcting soil acidity as has 3½ cwt. of calcium carbonate.

Cyanamide.—This is a synthetic fertilizer prepared by heating calcium carbide in a current of pure nitrogen. It is generally made in countries where cheap hydro-electric power is available.

The commercial material contains calcium cyanamide equivalent to 20·6 per cent. of nitrogen, together with carbon and various calcium compounds. It is the most "lime-saving" of the nitrogenous fertilizers, the final effect of applying 1 ton being equivalent to an application of 11 cwt. of calcium carbonate.

Nitrate of lime and cyanamide, though still manufactured and used in certain countries, were not available in Britain at the time of writing, and it seems unlikely, in view of the development in the home manufacture of other materials, that imports will be resumed.

Nitro-chalk.—This is a granular mixture of ammonium nitrate and calcium carbonate which contains 15·5 per cent. nitrogen. The ammonium nitrate has the effect of depleting the lime in the soil, but the calcium carbonate, which is present to the extent of 48 per cent., makes good this loss so that the net result of using the fertilizer is to leave the soil reaction unaffected. Nitro-chalk is an entirely satisfactory and safe source of nitrogen; it has an excellent texture for handling and sowing.

Ammonium nitrate, which is prepared synthetically, contains 35 per cent. of nitrogen and is therefore highly concentrated. As a fertilizer it is used in mixture because the pure salt is very deliquescent and there is some risk that it may explode.

Other Nitrogenous Fertilizers.—Urea in its commercial form contains 46 per cent. of nitrogen and is therefore extremely concentrated and has an advantage where transportation costs are high; its nitrogen is as efficient as that in sulphate of ammonia, but it cannot be mixed with superphosphate and under some conditions it is deliquescent. Resin-like polymers of urea, produced by treatment with formalin, are being increasingly used in the United States. They have the advantage that they release ammonia gradually over a considerable period and are used in cases where shoddy, hoof-and-horn, etc., were formerly preferred.

Ammonium chloride contains 26 per cent. of nitrogen. It has been used on the Continent and has been tried in this country; on the whole it is as satisfactory as the sulphate.

In the United States, anhydrous ammonia is now being used on a commercial scale as a fertilizer. It has the advantage of very high concentration (82 per cent. N) and ease of distribution. A hundred-gallon tank (containing 410 lb. of nitrogen) may be mounted on a tractor or implement and the ammonia released through high-pressure hose lines behind coulters. The ammonia must be placed at least 4 in. deep if loss by volatilization is to be avoided.

In this country trials are being made with the *gas liquor* which is a watery solution of ammonia, containing a variable amount of impurity. Its use, of course, would remove the necessity to convert the ammonia into sulphate, but the liquor is dilute and therefore costly to transport or store.

PHOSPHATE FERTILIZERS

Phosphorus is an essential constituent of protoplasm and is necessary for cell division; it is assimilated mostly when the plants are young, and it is very largely translocated to the seed during the process of ripening.

Supplies of phosphate stimulate root development in young plants, and they are consequently of great value in the case of a crop like turnips, which is shallow rooted and sometimes difficult to start, and on strong clay soils which do not permit of easy penetration and root growth. The tillering of cereals is stimulated by phosphates, and this leads to the development of more ears per plant and a better yield, but not to an increased proportion of grain to total crop. Another effect of phosphatic manuring is the promotion of early maturity and ripening; indeed its influence in this respect is just a little less marked than that of water scarcity, and in some cases it may shorten the growing period of cereals by ten days. Phosphates have a special value in promoting vigorous growth in leguminous plants, and they are largely used to encourage clover in pastures. Phosphate-deficient pastures, particularly in spring, have a characteristic dull, grey-green coloration, and there is a marked absence of leguminous plants.

In general, response to phosphates is relatively high in our wetter climates and on our more retentive soils. Indeed, in our drier areas, and on light soils, a few cases have been found where the concentration of available phosphate, due to frequent

and heavy applications, is harmfully high. Such cases are not uncommon under glasshouse conditions.

A shortage of phosphate stunts the root system and depresses tillering in cereals; in extreme cases of deficiency crops may not grow at all.

Most soils contain large reserves of phosphate, for the substance is firmly retained. Surface applications made on steep slopes and under wet climates may indeed be washed away in surface water, but the amount in drainage water is almost negligible. Phosphatic manures are mostly insoluble in water, and even those that are soluble at the time of application soon revert to an insoluble condition. On neutral or only slightly acid soils the phosphatic manures have a beneficial effect for several years, but on strongly acid soils there is rapid "reversion" to highly insoluble compounds. There is also reversion in cases where the soil contains free lime, but the resulting compounds are less stable. In general, and especially on the more extreme types of soil, frequent applications of relatively small amounts are more effective than large dressings at long intervals (see under **Placement**, p. 111). Land that has received regular dressings of phosphates accumulates a large amount in the top few inches of soil, but, for the reason given above, the crops nevertheless continue to respond to further applications. A few soils are so deficient in available phosphate that animals grazing on the herbage suffer from deficiency and develop bone abnormalities.

In the following text, except where the contrary is stated, the analyses of the phosphate fertilizers are given in terms of phosphoric anhydride (P_2O_5), and common usage is followed in designating this "phosphoric acid." Sometimes analyses are given as "phosphate," meaning the equivalent of tricalcium phosphate. The phosphate content of a fertilizer can be converted into the phosphoric-acid content by dividing the former by 2·2.

Bones are variable in composition, but ordinarily contain about 4 or 5 per cent. nitrogen, 46 per cent. calcium phosphate (22 per cent. P_2O_5), 7 per cent. calcium carbonate, 6 to 10 per cent. fat, and 10 per cent. water. Bones were first prepared for application to the land by crushing them into rough lumps in a grinding mill, but they are now usually sent to factories for extraction of their valuable fat and gelatine, and the residues only are converted into fertilizer. The nitrogen and calcium

carbonate in bones obviously give the material a value higher than that based on the phosphorus-content alone.

Bone Meal is prepared from bones that have had their fat extracted; it contains about 21 per cent. phosphoric acid, calculated as P_2O_5, and 4 per cent. nitrogen. The gelatinous matter which contains the nitrogen is slow to decompose; indeed the whole of the plant food in the meal is liberated very gradually, but this is considered to be an advantage on light and "hungry" land.

Steamed bone flour contains from 27 to 30 per cent. phosphoric acid and about 1 per cent. nitrogen: it is prepared by grinding bones that have had their fat and most of their gelatine extracted, and has a much finer texture than bone meal. The flour is so light that it is best applied in mixture with other fertilizers, and it is often included as a drier in compound manures. It gives very good results when applied to light land, and it becomes available at a rate intermediate between those of bone meal and superphosphate. It is better than superphosphate for soils poor in lime.

Superphosphate.—This is the most largely used phosphatic fertilizer. It is prepared by treating naturally occurring mineral phosphate with sulphuric acid in order to produce a water-soluble acid calcium phosphate. Superphosphate is obtainable as a grey friable powder or in granular form. The common grade contains about 18 per cent. soluble phosphate with a small amount—about 1½ per cent.—that is not water soluble. Superphosphate also contains a considerable amount of calcium sulphate and a small amount of unaltered tricalcic phosphate. When the manure is kept for a considerable period it tends to revert to insoluble phosphate and always reverts when it is applied to the soil; but as it is well distributed before reversion takes place it is the most readily available and quickest acting of the phosphatic fertilizers for soils that contain free calcium carbonate. It is wasteful to use superphosphate on sour soil, because the latter contains soluble iron and aluminium salts which unite with and precipitate the fertilizer in such a stable form that it is practically no longer available for plant nutrition. When superphosphate is first applied to the soil it produces an acid reaction, but, contrary to popular belief, it has no permanent effect in increasing soil acidity.

"Triple" superphosphate is made in two stages: the ground rock phosphate is treated with sulphuric acid in such proportions

that phosphoric acid (H_3PO_4) and calcium sulphate are formed; the phosphoric acid is then filtered off and reacted with further ground phosphate. The final product, as made in Britain and from which the calcium sulphate has been eliminated, contains 45 per cent. phosphoric acid (P_2O_5). Its high concentration gives it an important advantage in areas far remote from phosphate supplies.

Silico-phosphate is produced from a mixture of mineral phosphate, soda ash, and sand by roasting in a kiln at 1400° C. It contains the equivalent of 33 per cent. of P_2O_5—*i.e.* it is about twice as rich as superphosphate. The greater part of the phosphate is readily available. It may be that the process will replace the acid treatment that produces superphosphate.

Basic Slag.—Basic slag is a by-product in the manufacture of steel. The bulk of the iron ore in this country contains a considerable amount of phosphorus, which passes into the pig-iron when the ore is smelted. In order to make the iron into high-quality steel the phosphorus must be removed. This removal was first achieved in 1879 by the Bessemer process, in which air is blown through the molten iron to which lime has been added. In the consequent oxidation the phosphorus combines with the lime and forms on top of the metal a scum, which is poured off and solidifies. This is basic slag. The various steel-making processes produce slags of varying phosphate-content, the range being from 6 to 20 per cent. Moreover, a varying proportion of the total phosphate is soluble in 2 per cent. citric acid, and citric solubility is rather closely related to availability of the phosphate to plants. The range in citric solubility is wide—from about 30 to about 95 per cent.

A further point is that availability of the phosphate depends on fineness of grinding. This is expressed as the percentage, by weight, of the powder that will pass through a sieve with 10,000 holes per square inch. There is in general very little difference in availability to the plant between water-soluble and citric-soluble phosphate. On the other hand there is, in many soils, a very marked difference between citric-soluble and insoluble phosphate. The vendor of slag is required to state the phosphoric-acid content, the fineness of grinding, and the amount of phosphoric acid soluble in 2 per cent. citric acid. The buyer must bear in mind that slags of low solubility are worth much less than high-soluble slags of otherwise similar quality.

The following figures for a number of different slags illustrate the point :—

	Total P_2O_5 per cent.	Citric Soluble per cent.	Percentage of Citric Soluble in Total Phosphate
(1) . .	17·6	15·6	89
(2) . .	10·6	10·2	96
(3) . .	9·5	7·7	81
(4) . .	11·7	3·8	32
(5) . .	8·1	3·3	41

Slags also contain lime equivalent to about half of their weight of calcium and magnesium carbonates as well as certain trace elements, particularly manganese.

The poorer qualities of basic slag are rather slow in action for arable crops, and it may be some time before their effect is seen on grassland; indeed, low-solubility slags should be used only in areas of high rainfall and on fairly heavy and rather acid soils. On the other hand, high-soluble slag with a high phosphate content is suitable for arable crops and gives beneficial results almost immediately. The combination of phosphoric acid and calcium enables slag often to produce a striking improvement in grassland. This it does by encouraging the growth of clover and indirectly bringing about an accumulation of nitrogen which benefits the other herbage. The best results are obtained when slag is applied to damp, heavy land. On light land and under dry conditions its results may be surpassed by the combined effect of superphosphate and lime.

Mineral Phosphate.—Rock phosphates—derived from marine animals or formed by the leaching of bird guano into underlying limestone—vary in purity and hardness. They are found in beds in various parts of the world and form our chief source of phosphoric acid. For example, the following phosphates have been used largely in this country for agricultural purposes :—

South Carolina	phosphate	containing	about	27	per cent.	phosphoric	acid.
Ephos (Africa)	,,	,,	,,	30	,,	,,	,,
Florida	,,	,,	,,	30	,,	,,	,,
Gafsa (African)	,,	,,	,,	26	,,	,,	,,
Nauru (Ocean Island)	,,	,,	,,	40	,,	,,	,,
Tunisian	,,	,,	,,	25	,,	,,	,,

It has already been pointed out that rock phosphates are used in the manufacture of superphosphates. Considerable quantities are, however, being finely ground and used directly as a fertilizer, particularly for grassland. The fineness of grinding is very important and the best results are obtained when the material is crushed so fine that a large proportion will pass through a screen with 14,400 holes to the square inch (120 mesh sieve). The fertilizer does best when employed on acid soils and in wet localities, the reason being that the wetness and the acidity cause the insoluble phosphate to become more quickly available. It is best to apply the phosphates some time before they are required to act, and it is unlikely that they will have much effect on a crop such as barley, which has a short growing season. Mineral phosphates usually contain from 2 to 12 per cent. of calcium carbonate.

POTASH FERTILIZERS

Potash is widely distributed and occurs in association with the clay fraction of all soils, but it is often deficient in soils of a sandy nature. Even on rich soils, however, the potash may not be sufficiently available to supply the needs of crops like potatoes and mangolds, which store up large quantities of carbohydrate material. In such cases soluble potash compounds may be profitably applied. The potassium salts commonly used as fertilizers are all highly soluble in water, but the potassium ion enters into firm combination with the soil colloids. In very sandy soils of low humus-content potash is to some extent washed down beyond the reach of the shallower rooting crops, and some appears in the drainage waters. At the other extreme, on chalk soils, some of the applied potash may be fixed in combinations so strong that it is unavailable to plants.

The potash required by plants is very largely assimilated in the early stages of growth, and it remains mostly in the stems and leaves. Potassium is associated with the efficiency of the leaves in carbon fixation, and its action is linked with that of nitrogen in plant development and in the maintenance of a satisfactory balance of carbon and nitrogen in the tissues. Heavy dressings of nitrogen fertilizer with insufficient potash produce large but relatively inefficient leaves and a general "softness" and susceptibility to disease, and cereals tend to lodge. With adequate potash, however, the plant has a better tone and vigour, an

improved capacity for assimilating carbon, and the power of doing well in a cold, dull, and unfavourable season when crops getting no potash fail to attain normal yields. It is only by using potash in conjunction with nitrogen that crops like potatoes, sugar-beet, and mangolds can produce the big tonnage per acre that is now common. Plants suffering from potash starvation often develop scorched-looking leaves that die prematurely at the tips and edges. Potash differs from both nitrogen and phosphate in distinctly increasing the weight of individual cereal grains, and it is therefore useful in producing a plump, bold sample in a crop like barley. Potash slightly increases the sugar-content of beet; it often brings about a remarkable improvement in clover and other legumes and enables them better to withstand the winter. The liberal use of potash may be inadvisable with a crop like early potatoes, because by promoting the vigour of the leaves it may prolong growth and delay the time of lifting.

The potash-requirements of plants were formerly met by natural soil reserves and by returning to the land the residues of previous crops or the ashes of wood, etc. Potash fertilizers were little used until after the discovery in 1861 of deposits of potash salts in Germany. While Germany remains the largest producer, potash salts are also worked in France, U.S.A., Spain, Poland, Palestine, and Russia. A very large deposit exists in the neighbourhood of Whitby in Yorkshire, which, however, is at great depth. The potassic fertilizers are sold either as refined salts, crude crushed material, or as a mixture of crude and refined salts graded to contain a certain percentage of potassium.

The potash fertilizers available in Britain at the time of writing were as follows :—

	Minimum K_2O	Potassium Chloride	Potassium Sulphate	Sodium Chloride
Muriate of Potash .	60	95	...	3
,, ,, .	50	80	...	15
,, ,, .	40	63	...	25
Sulphate of Potash .	48	...	90	...

As a rule, sulphate of potash is used in manuring potatoes for high quality, for fruit trees, and for glasshouse crops. High-grade muriate of potash may be used for practically any farm crop, and it is just as effective as the sulphate, except perhaps from the

point of view of quality. The lowest of the three grades of muriate (sometimes called potash manure salts) contains 25 per cent. of common salt and is therefore to be preferred for sugar-beet, fodder-beet, and mangolds, and probably also for grass. Common salt itself often produces a marked response in the case of mangolds and sugar-beet, which fact was formerly explained on the hypothesis that the sodium replaced and set free potassium ions in the clay fraction. It has now, however, been definitely established that sodium itself is an active nutrient for these particular plants. Because its production involves a chemical process, sulphate of potash is more costly per unit than the muriates.

The colour of the potassic fertilizers is very variable, and the pure salts may be either crystalline or powdered, but they are all easy to spread; they may be stored for any period without loss, though in time they become somewhat lumpy and may have to be broken up before distribution. The lower grade muriates are most prone to cake or become pasty.

COMPOUND FERTILIZERS

Fertilizer manufacturers and merchants prepare mixtures of nitrogen, phosphatic, and potash fertilizers with varying proportions of the three nutrients. Such "compounds" naturally cost more than the equivalent quantities of individual fertilizers, but have the advantage of better physical condition than most farm-made mixtures. In some cases they are sold in granulated form. Granulation is secured by putting the ingredients through a special process whereby they are pulverized down to a certain degree of fineness, mixed with enough water to cause them to form granules, and then finished off in a drier-hardener followed by a cooler. Before deciding to purchase compounds the farmer should assure himself that the balance of nutrients is suitable for his particular soil and crop, and that the price is not excessive (see p. 109).

NATIONAL COMPOUND FERTILIZERS

When the compounding of fertilizers is left to individual merchants it is obvious that a bewildering variety may be offered to farmers. While many of the larger manufacturers and certain

merchants continue to offer a wide variety, most of the farmers' needs are now met by the various National compounds. The first group are simply mixtures of two, three, or more of the materials described above—in most cases sulphate of ammonia, superphosphate, and muriate of potash, with some steamed bone flour as a drier. One, however, is a mixture of ground mineral phosphate and muriate of potash.

The second group is obviously more concentrated than anything that could be secured by mixing the common materials so far described. Concentration is achieved by including either ammonium phosphate or triple superphosphate.

It may also be that so-called nitro-phosphate, produced by treating phosphate rock with nitric acid, will become available in the future.

Concentrated fertilizers are specially suited for application by the combine drill, but some farmers use them, for general purposes, in preference to ordinary compounds.

The following table gives the composition of the "National" compounds which were available in the spring of 1954:—

	Percentage of Nutrients			
	Nitrogen (N)	Soluble Phosphate (P_2O_5)	Insoluble Phosphate (P_2O_5)	Potash (K_2O)
National No. 1	7·0	6·5	0·5	10·5
,, No. 3	6·0	11·0	1·0	...
,, No. 5	4·0	9·25	0·75	8·0
,, No. 6	6·0	8·25	0·75	6·0
,, No. 7	...	12·0	1·0	13·0
,, No. 8	...	...	20·0	10·0
,, No. 9	9·0	8·5	0·5	...
,, No. 10	...	9·25	0·75	20·0
Compound containing ammonium phosphate	12·0	11·9	0·1	15·0

TRACE ELEMENTS

Manganese deficiency affects chiefly sugar-beet, mangolds, potatoes, oats, wheat, peas, and kale. The commonest cases are those in which soils of high organic-matter content have been limed more heavily than necessary, the neutralization of the acid condition tending to throw the soil manganese out of solution.

7

The symptoms depend on the crop: mangolds and sugar-beet show blotching and necrosis of the foliage, curling of the leaf margins, and a greatly reduced yield; oats exhibit spotting and striping of the leaves in the early stages, and in severe cases the crop may have disappeared by June; in potatoes dark brown spots appear alongside the leaf veins; peas develop corky patches within the actual seed. To correct manganese deficiency, 20 to 50 lb. of manganese sulphate per acre may be applied as a fertilizer. Crops showing the need for immediate treatment can be saved by spraying with 10 lb. of sulphate per acre dissolved in 100 to 150 gals. of water.

Boron deficiency affects a number of crops, particularly sugar-beet, mangolds, and brassicas. The symptom in beet and mangolds is a discoloration of the leaves and petioles, which later shrivel away as the disease descends and rots the crown. In turnips and swedes the tissues within the bulb break down and rot, the condition being known as Raan or Brown Heart. The preventive is to apply 14 to 20 lb. of borax per acre mixed with fertilizer or any convenient material that will provide sufficient bulk for even distribution.

Magnesium deficiency has been observed on a wide range of crops including potatoes, sugar-beet, and brassicas. A yellowing of the foliage usually occurs, and is to be expected as magnesium is a normal constituent of chlorophyll. The remedy is to apply magnesian limestone or, if quick results are required, magnesium sulphate.

Minerals are of great importance in animal nutrition (see Part III, Chapter II). In this respect there are minor elements which, when deficient or in excess, have no apparent influence on the herbage, but nevertheless profoundly affect the health of the grazing stock. To take but two examples, sheep may pine on certain grasslands for lack of cobalt and, on the "Teart" pastures of Somerset, cattle scour because of an excess of molybdenum.

ORGANIC MANURES

Farmyard Manure.—Farmyard manure is the best all-round soil improver. It does not enter into competition with the artificial manures but should be used in conjunction with them, and its value is greater than can be assessed by the consideration of its

content of plant nutrients. Not only does it supply to a greater or less extent all the plant foods that are likely to be deficient in agricultural land, but it improves the texture and tilth of the soil, and increases its capacity to hold water, and to retain soluble nutrients that would otherwise be washed down beyond the root range of crop life. It has been estimated that the total amount produced in Britain annually exceeds 40 million tons, and that this quantity provides about as much nitrogen and potash as is applied in the form of fertilizers. Dung, however, is a poor source of phosphate, providing only about a sixth of the total supply.

While this total quantity is large, it is sufficient to provide an ordinary dressing—12 tons per acre—only at intervals of six or seven years over the total acreage of farm land.

Dung consists of a mixture of litter and the excreta of different kinds of stock, and in its fresh condition is therefore made up of straw, fæcal matter that has resisted the action of digestion, and urine, which is a solution of substances that have been absorbed from the food into the blood and finally excreted from the system. Urine contains about half of the nitrogen and most of the potash voided by the animal; it is the richest, most quickly available, and most easily lost portion of the manure. The solid portion of the dung contains the other half of the nitrogen, which is in a form slow to decompose, and most of the phosphoric acid and lime of the food. The composition of "made" dung is very variable, but on an average 1 ton of farmyard manure contains some 12 lb. of nitrogen, 5 lb. of phosphoric acid, and 12 lb. of potash. This is equivalent to about $\frac{1}{2}$ cwt. of sulphate of ammonia, $\frac{1}{3}$ cwt. of superphosphate, and $\frac{1}{5}$ cwt. of muriate of potash, but so much of the fertilizing materials, particularly the nitrogen, is locked up in slowly available forms, or is lost in storage and handling, that the value of the dung in plant nutrition is probably no higher than half the equivalent quantity of artificial fertilizer. Again, its content of phosphoric acid is too low to give it the right "balance" for average conditions; on the other hand, practically all the potash contained in the animal's food is excreted in the urine and, if the latter is preserved, dung has a considerable value on account of its potash content. The quality of dung is influenced by a number of factors which are considered in some detail below:—

1. *The Food of the Stock.*—With ruminants and horses on

ordinary rations, about half of the dry matter fed is returned in the manure, the remaining portion being built up into the animal's tissues or destroyed by respiration and fermentation in the production of heat and other forms of energy. The proportion will, of course, vary according to the type of ration fed. Thus the proportion of dry matter that is returned in the dung is nearly 60 per cent. for coarse straw, about 45 per cent. for average hay, and only 15 to 20 per cent. for roots and cereals and low-fibre oil-cakes. With pigs and poultry, which are ordinarily fed on more highly digestible foods, the proportion of dry matter that reappears in the manure is less. As the oil and starch contents of the food have no influence on the value of the manure, only the nitrogen and ash in the animal's diet require consideration. Oil-cakes and leguminous foods are rich in all the valuable manurial constituents and, because of their high nitrogen-content, produce dung that ferments readily and becomes quickly available when applied to the soil; cereal grains and hay produce manure of average richness, while turnips and straw give rise to a substance that is somewhat poor in quality and ferments and becomes available but slowly.

2. *The Litter.*—The chief value of litter is its power of absorbing moisture and volatile decomposition products. The ordinary cereal straws form the most common litter of the farm: they should be used unsparingly if loss of urine and ammonia is to be avoided, and they decompose readily in the field with the liberation of plant foodstuffs. A ton of straw will generally soak up enough moisture and retain enough fæcal matter to form from 4 to 6 tons of fresh manure. Moss litter is superior to straw in its power of absorption, but is slow to decay and less suitable for improving the texture of heavy land. When bracken is available it forms excellent litter, for although it does not wear as well as straw it is richer in potash. Sawdust and shavings are relatively unsatisfactory since they decay in the soil very slowly. Contrary to what is rather widely believed, however, they have no harmful effects.

3. *The Age of the Animals.*—Young growing animals absorb a great deal of the nitrogen and ash of their food to build up muscle and bone, and may return less than half to the manure heap in their excrement. On the other hand, when well-grown animals are being fattened their live-weight increase consists almost entirely of fat, which contains no manurial substance and

is therefore formed without loss to the manure. Indeed, fattening bullocks may remove less than 5 per cent. of the nitrogen and ash from their food.

4. *The Kind of Animal.*—Horses produce manure of a dry nature; it is called "hot," as it ferments rapidly and does not last long. It should be well mixed with litter or other dung, as it tends to lose its nitrogen quickly in the form of ammonia. Cows' manure is of a very watery nature; it is "cold," *i.e.* decomposes very slowly. The manure obtained from cows may be likened to that of young stock, because in the production of milk and the development of the unborn calf a great deal of nitrogen and mineral matter is extracted from the food and never finds its way to the dung heap. Cows produce a great bulk of urine and, as litter is seldom available in large quantities on a dairy farm, it is particularly desirable to construct a tank for the preservation of the fluid, which can be removed periodically and distributed over the pastures. The excrement of bullocks is superior to that of cows, the best being obtained from fattening beasts. The manure of pigs resembles cow dung in being cold and slow to ferment, while sheep's excrement is concentrated and rots freely.

5. *The Method of Making and Storing.*—It is generally impracticable and often undesirable to manure crops with fresh excrement and litter. The dung has usually to be stored for considerable periods, and during this time it rots until it has the desirable texture of "made" manure, losing much of its carbonaceous matter by fermentation and oxidation. Unfortunately, these changes are in practice always accompanied by the loss of a considerable portion of the most active and valuable nitrogenous substance of the urine. Although this cannot be obviated without using far more litter than is ordinarily available, it is to the interest of the farmer to reduce the loss to a minimum.

What is the nature of the decomposition which goes on in the manure heap? The most obvious change is the alteration of the straw, etc., into brown structureless humus. This decomposition is due to the action of bacteria under mixed aerobic and anaerobic conditions, and results in the loss of at least 20 per cent. of the dry matter of the manure. The loss of non-nitrogenous organic matter is of little importance, but the loss of nitrogen is serious and extremely costly. Dung contains the nitrogen of the straw, the nitrogen of the fæces which has resisted the process of digestion, and the soluble nitrogenous compounds of the liquid excrement.

Investigations have shown that it is the nitrogen of the urine only that is liable to be lost. When urea ferments it is converted into ammonium carbonate, which in turn may decompose with the liberation of ammonia, and even of free nitrogen. Now it has been shown that litter is capable of "fixing" a certain proportion of this ammonia in a stable non-ammoniacal form, but cannot fix more than about 0·72 part of nitrogen per 100 of dry straw. A further quantity of ammonia is retained by physical means when the dung is in a well-preserved, moist condition, but it can be washed out by percolating water and is entirely lost when the manure is dried. It would seem, then, that the ammoniacal nitrogen is so liable to be lost in the carting and spreading of the dung that it is desirable to have as much as possible in the stable state. This can be brought about by using sufficient litter to fix the whole of the nitrogenous matter of the urine, but dung so made has the disadvantage of being very slow to yield its nitrogen to plants. Nevertheless, in systems of farming where bullocks are looked upon as a means of converting straw into manure, it is more profitable to keep a limited number of animals and to supply them with ample litter than to attempt to increase the quality of the manure by heavy stocking and liberal cake feeding.

Farmyard manure that has been "made" may contain a bigger percentage of nitrogen than before rotting took place, but it will normally have a smaller total of nitrogen than was present in the original mass. Up to a point it is desirable that carbonaceous material should be broken down, for, as has been shown in Chapter II, fresh straw added to the soil so stimulates certain bacteria that they assimilate the nitrates from their surroundings and may thus cause temporary infertility. Rotting has the further advantage that the accompanying heating destroys weed seeds. After a moderate degree of rotting has taken place, however, further loss of dry matter merely reduces the bulk of cellular material that is so useful in the mechanical retention of ammoniacal nitrogen, and leaves less material to improve the texture and water-holding capacity of the soil. A minimum loss occurs in the manure-heap under the following conditions:—

1. Anaerobic conditions should be induced as far as possible by keeping the heap moist and well compacted. This is best attained by keeping the animals in boxes or courts, allowing the dung to accumulate beneath them, and adding fresh litter daily so that the animals rest on a dry surface. Thus the air is excluded,

the heap is moistened by liquid excrement, and the evaporation of ammonia is reduced to a minimum.

2. Where rain-water percolates through the heap it washes out much of the potash and some of the soluble nitrogen compounds; therefore, at least in areas of high rainfall, the manure should be stored under a roof. Under other conditions, as where manure is being kept in deep heaps that are liable to dry to a considerable depth below the surface, wetting by rain will keep the surface moist and reduce the loss of nitrogen. In stock yards, when insufficient litter is employed to absorb the urine, an impervious bottom will prevent the escape of liquid to the subsoil or drains.

3. Where an excessive amount of urine is produced, as is the case in dairy herds, special tanks should be constructed into which the liquid excrement may be led by a system of drains and from which washing water can be excluded. The tanks may be emptied from time to time and their contents distributed over pastures or young corn crops. Where the urine has been diluted with washing water, as in many cowsheds, the labour cost of handling the liquid may be greater than its value. Drainage can, however, be so arranged as to collect the valuable liquid and allow the very dilute washing water to run to waste. A thousand gallons of liquid manure are equivalent to about 3 cwt. of kainit and 100 lb. of sulphate of ammonia.

The Application of Farmyard Manure.—The maximum value is obtained from dung when it is carted to the fields as soon as it is made, and ploughed in; but this is practicable only at certain seasons of the year. Under ordinary conditions dung must necessarily be accumulated for a considerable time. It may be applied to the land after harvest, carted and spread during periods of hard weather during the winter, or placed in the drills for certain root crops in spring. Certain factors require consideration before a system of application can be evolved: (1) The great bulk of farmyard manure is accumulated during the house-feeding period from October to April, and, if possible, the whole of this manure should be applied to the land before the last crops are sown in the spring, because the heat of summer is inclined to desiccate the heaps and cause very great loss. (2) As ploughing is generally completed in January, only that portion of dung accumulated from October to December is available for spreading on the stubbles, and manure made from January to May has to be

applied in ridges for the root crops. (3) The only manure available for application to the stubbles after harvest is that made and stored during the summer, provided, of course, that all the winter dung has been applied.

In practice most of the dung should be applied during autumn and winter when low temperature and high humidity reduce the activity of fermentation and the volatilization of ammonia. Further economy is effected by spreading and ploughing it in as quickly as possible.

However, local climate may determine the best policy. In the wet, cool climate of our northern and western districts the first of the dung is applied to the stubbles in autumn and winter, advantage being taken of frosty weather to get the manure out to the fields. By applying the remainder of the material in ridges, the courts are completely emptied before turnips are seeded. In places where a heavy winter rainfall is likely to wash away the soluble constituents of the manure, the best results are got when the dung is applied in the drills in spring. But in dry southern and eastern localities it is found that the application of dung in the drills for root crops is liable to dry out the soil, and the manure made after New Year is usually held over until the corn crops have been cleared in the autumn.

The liquid manure accumulated in tanks during the feeding period gives the best results when applied either periodically throughout the growing season to rotation grasses or as a top dressing to cereal crops in the spring. If it is too strong, however, and especially if the soil is dry, it is inclined to " burn " the herbage and may have to be diluted. A preliminary trial should be made on a small scale, and if no ill-effects follow the tanks may be emptied forthwith. A good deal of ammonia may be lost if the liquid is applied in hot, dry weather.

Straw and other Composts.—Straw in cattle courts and dung heaps breaks down readily because urine provides the water, nitrogen, and salts needed by the bacteria that oxidize the carbon compounds. Straw thrown out in a heap will not readily decay because, although it may be wetted by rain, it contains insufficient nitrogen, etc., to be a suitable medium for active fermentation. However, straw or other similar material can be broken down by the addition of water, nitrogenous salts, and basic material (to check the accumulation of acids), which make the mixture as a whole a suitable one for the action of cellulose-

destroying organisms. Special reagents sold by various firms may be used; alternatively a mixture of ¾ cwt. each of sulphate of ammonia and ground limestone, and ½ cwt. of superphosphate, may be applied per ton of dry straw. This will, in the presence of sufficient added water, cause rotting to take place and yield a product which closely resembles farmyard manure, and which has approximately equal fertilizing value. About 800 gals. of water are needed per ton of straw, and a difficulty is that, to begin with, the straw will not absorb this quantity, so that watering has to be repeated at intervals. Compost has sometimes been made by placing the straw heap so that it is watered by rainfall, building up layer by layer as the previous material has been sufficiently wetted and adding the necessary material to promote rotting. But since it takes 3 or 4 in. of rain to wet sufficiently a 1 ft. layer of tramped straw, the process is very slow. It may, however, be practicable to sweep wet straw to a compost heap in the field.

In making a straw compost heap the base should be calculated at the rate of about 40 sq. ft. per ton of straw. The height of the mass will then be about 7 ft. when built, and about 3 ft. after settling. Each ton of straw will produce about 2 tons (or 4 cub. yds.) of compost.

If straw has to be ploughed in before it is rotted it is desirable to apply 1 to 1½ cwt. of sulphate of ammonia per acre, in addition to that normally required by the following crop, to ensure that it does not produce temporary infertility by fixing all the available nitrates. Again, the long stubbles left by combines will rot more readily after ploughing if the cereal has been under-sown with a nitrogen-rich species such as trefoil. Ploughed-in straw gives good results with potatoes and causes little trouble in the case of spring-sown cereals which do not require a very fine and very firm seed-bed. For other crops compost is to be preferred.

Urine and nitrogenous fertilizers can also be used to help rot down composts of waste organic materials. Straw, road scrapings, scourings from ditches, turf, leaves, etc., may be built into heaps with alternate layers of earth and turned over once or twice until sufficiently decomposed to be suitable as manure. The inclusion of fish, blood, and other animal matter will greatly enrich the compost. Market-garden waste, such as weeds and unmarketable greenstuff, makes excellent compost. Naturally it does not require much, if any, wetting, and only small quantities of nitrogen,

etc., are required to promote rotting, the amount varying with the proportion of stemmy and lignified matter in the refuse.

Poultry Manure.—The output of manure from poultry can be computed on the basis that the fresh manure is approximately equal in weight to the dry food consumed by the birds. In the case of a laying hen this will be about ¼ lb. per day. If the fowls are on range, about half the droppings will be got in the houses. The fresh material contains approximately 35 per cent. dry matter, 2 per cent. nitrogen, 1 per cent. phosphoric acid, and 0·5 per cent. potash. When the manure is air-dried the percentage of dry matter is raised to 85 or 90, and there is a corresponding increase in the plant nutrients, except nitrogen, some of which is lost in the process of drying. While the above figures apply to average samples of poultry manure, the quality of course depends on whether the birds are growing, fattening, or laying. Again, the manurial value may be reduced owing to the presence of chaff, sand, etc., which has been used as litter in the houses.

The manure is quickly available and it should be handled with care to prevent loss of nitrogen. If possible, the droppings should be dried or mixed with dry soil to facilitate spreading. The most valuable samples are those that have been carefully dried and then pulverized; they may contain over 4 per cent. of nitrogen and they are easily worked into the soil. It will be obvious that, owing to the difference in the relative proportions of the materials, poultry manure will require supplements, in the form of fertilizers, different from those used in conjunction with dung. Substantially more potash must be used, and less nitrogen will suffice.

Guano.—The original guano, consisting of an accumulation of the droppings, feathers, and remains of sea birds, was obtained from a number of rainless islands off the coast of Peru. It contained about 12 per cent. nitrogen, 10 per cent. phosphoric acid, and 3 per cent. potash, all of which were readily available as plant food. Many other guanos have since been imported, but they are nearly all poorer in nitrogen than the original substance.

Phosphatic guano has originated like ordinary guano, but in a rainy climate. It has been washed almost completely free of nitrogen, and some samples are practically pure calcium phosphate.

Equalized guano is a naturally-occurring low-grade guano made up to contain a given percentage of nitrogen by the addition of sulphate of ammonia.

Fish guano is not a true guano, but is prepared from fish offal by extracting the valuable oil and grinding up the dried residue. Its composition varies, but an average analysis is 9 per cent. nitrogen, 7 per cent. phosphoric acid, and 0·6 per cent. potash.

All the guanos are thoroughly reliable and useful manures, though they may be rather expensive in comparison with simple manurial salts. Many farmers, however, and particularly those on light land, maintain that slow-acting organic manures of this kind produce better results than quick-acting soluble substances.

Shoddy.—This is a waste material—produced in the manufacture of woollens—which is very variable in quality and may contain from 3 to 15 per cent. of nitrogen according to the proportion between actual wool and such practically worthless constituents as cotton and cellulose fibres. It is largely used in hop gardens and to some extent also for soft fruit. Common dressings are at rates of 1 or 2 tons per acre. It is, as would be expected, relatively slow-acting.

Soot.—Soot contains normally about 4 per cent. of nitrogen in the form of sulphate of ammonia, but may contain considerably more. It is quick to act on the soil and is largely used as a spring dressing for vegetable crops, about 25 bushels, equivalent to 1¼ cwt. of sulphate of ammonia, being applied to the acre. Its dark colour improves the temperature of the soil, and it may be useful in checking the activities of slugs. Its chief disadvantage is its dirtiness, and farmers are almost obliged to supply their labourers with special clothes to wear when handling it.

Seaweed.—Seaweed has been used for generations along the coastal districts of Great Britain and Ireland for improving the fertility of the land. Different species of weed have different values, but a ton of average mixed material contains 9 lb. of nitrogen, 25 lb. of potash, and 2 lb. of phosphoric acid. It is thus about as valuable as dung, but is richer in potash and poorer in phosphates. In certain parts the seaweed is specially cut and harvested, but along most rocky coasts it is carried ashore by undercurrents during stormy weather in autumn and winter. Seaweed is particularly useful for potatoes, and is largely used in the early potato districts of Ayrshire, Cornwall, and the Channel Islands. It may be applied at the rate of 20 to 30 tons per acre.

Other Organic Manures.—A very large number of waste organic substances, such as dried blood, hair, ground hoofs and horns, rape cake and damaged oil-cakes, spent hops, etc., are

used for manurial purposes. The value of these materials depends on their content of plant nutrients, and in the case of a tough substance like horn, on the fineness of grinding. The relatively slow production of nitrates from manures in this class is often an advantage on light land and in certain branches of horticulture.

Town refuse can be obtained in certain districts; it is very variable in composition and is on the whole less valuable than farm manure; it is sometimes used with the main object of improving the texture of heavy land. It should be valued on the basis of its analysis. However, it is also possible to obtain standardized and pulverized products from which tins, crockery, etc., have been removed. Sewage sludges are also variable in composition, and since the dry-matter content is always low, only the richer types are worth the cost of transportation and distribution. It may be composted with straw or with town refuse.

Green Manuring.—Green manuring consists of cultivating a crop and ploughing it in for its manurial value. As a rule only catch crops—*e.g.* white mustard, trefoil, and Italian ryegrass—are grown for this purpose, and the system is seldom practised except where it is necessary to improve the water-holding power of a light, hungry soil, or where, on rich land, there is a risk of loss of nitrates between the harvesting of one crop and the sowing of the next.

In light soils green manures decay with great rapidity, particularly when the plant grown for the purpose is a legume or where from other causes the nitrogen-content is high. It is therefore important that the soil should be occupied by plant roots soon after the material is ploughed in. It may be repeated that the most effective of all organic materials, in improving soil texture, is the sod produced by a well-grown ley.

THE PURCHASE OF FERTILIZERS

On account of the large number of manures available, and their varying composition, it is necessary to have a system by which different fertilizers can be compared on a basis of price and value. This comparison is made on the cost of 1 unit, which is 1 per cent. of a ton, and is obtained by dividing the price of a ton by the percentage of the active manurial ingredient.

For example, if 18 per cent. superphosphate costs £12 per ton,

$$\frac{£12}{18} = 13\text{s. } 4\text{d.} = \text{cost per unit of soluble phosphoric acid.}$$

The cost is compared with corresponding unit prices of phosphoric acid in other fertilizers, and provided it is suitable for the purpose in view the cheapest source should be chosen.

In the case of mixed fertilizers, however, which contain two or more manurial ingredients, the comparison and valuation are somewhat different. With regard to the unit values it is customary to assume that the value of the nitrogen and potash is the same as in the nitrogenous and potassic manures, the soluble phosphates the same as in superphosphate, and the insoluble phosphates the same as in slag or mineral phosphate.

At the date of writing, the unit value of nitrogen was 16s., that of water-soluble phosphoric acid 14s., and that of potash 7s. What is the value per ton of a mixed manure containing 9 per cent. nitrogen, 7 per cent. phosphoric acid, and 6 per cent. potash?

9 units of nitrogen at 16s.	£7	4	0
7 ,, phosphoric acid at 14s.	4	18	0
6 ,, potash at 7s.	2	2	0
Value per ton . . .	£14	4	0

Therefore if the market price of the manure is much more than £14, plus the cost of bags and mixing, it is too dear.

Unit values cannot be taken absolutely literally, however, and must be used for guidance only, as many manures which have a physical action on the soil, or are particularly suitable for certain purposes, have a value that cannot be assessed by comparison with the chemical fertilizers. The "lime-saving" or "lime-wasting" effect of the fertilizer has also to be taken into account. For example, a unit of nitrogen applied in the form of sulphate of ammonia will result in the loss of nearly 1 cwt. of calcium carbonate, whereas a unit applied as nitrate of soda will save rather more than ¼ cwt. of this substance.

Mixing Fertilizers.—When fertilizers are mixed together for convenience of application the following are some of the more important precautions that should be taken:—

1. Materials containing active lime (slag and cyanamide) should not be mixed with dung, guano, or ammonium salts (sulphate of ammonia and nitro-chalk), otherwise ammonia will be lost.

2. Dissolved phosphates such as superphosphate should not be mixed with manures containing lime or calcium carbonate,

which would cause the soluble phosphate to revert to an insoluble form.

3. Nitrates should not be mixed with substances containing free acid, *e.g.* acid sulphate of ammonia or badly made superphosphate, because the acid will cause a loss of nitrogen. Fortunately, samples of "acid" fertilizers are now rare.

4. The effect of the ingredients on the physical condition of the compound must also be taken into account. Soluble salts attract moisture from the air and have to be mixed with a drier in order to secure a sufficiently friable condition for sowing. For example, sulphate of ammonia and superphosphate when mixed together will cake unless a "drier" is added. Again, there are substances—*e.g.* nitrate of lime—that can be mixed only if sowing is to follow immediately.

Lack of space prevents consideration being given to all the possible mixtures of manurial salts, and readers requiring further information are referred to the technical advisers attached to the large fertilizer concerns.

For thorough mixing, the manures, in the proper proportions, should be put down layer upon layer on a suitable floor. The flat-topped heap made in this way should then be shovelled over by starting at one end and cutting vertically downwards through the different ingredients. This turning may be repeated until the material is sufficiently well mixed, and it is also well worth while to pass the mixture through a riddle in order to remove lumps, which are then easily broken down. A good riddle for this kind of work is the type of screen employed by builders for riddling sand and gravel. This screen is propped up at an angle and the material is thrown against it so that the small particles pass through and the lumps roll back to the feet of the operator.

A number of firms make machines for mixing manures, but the cost of such a mixer can only be justified on a very large farm. Practically all manure merchants employ mechanical mixers and they are usually prepared to mix fertilizers for a few shillings per ton. Their products are frequently superior in texture to those mixed on the farm. This is largely due to a wider use of "driers" and "conditioners," which in themselves may have no manurial value, but it is also attributable to the experience of the firms in dealing with the considerable differences in physical condition that are got in different batches of some of the common fertilizers. Concentrated manures and granular compounds are relatively

clean to handle and easy to distribute; moreover, they do not cake.

The best ordinary compound fertilizers are generally made up of sulphate of ammonia, superphosphate, and one or other of the potash manures, together with a small amount of a drier such as steamed bone-flour. Even carefully selected materials of this sort tend to cake slightly after they are mixed, thereby causing some difficulty when the manure is being sown. This trouble can be overcome if the fertilizer is mixed and sown on the same day, or, if this is not convenient, the manure can be riddled once more after the caking is completed, when it will be found that it will retain its fine free texture. Basic slag and potash salts may be mixed for land that has a tendency to sourness. Ready-mixed "potassic basic slag" is available on the market.

Granulated Fertilizers.—The most convenient form of chemical fertilizers is in granules of about the size of a wheat grain. Such material is much less liable to cake than a powder, and is easy to distribute uniformly. Increasing amounts of compound fertilizer are sold in granular form.

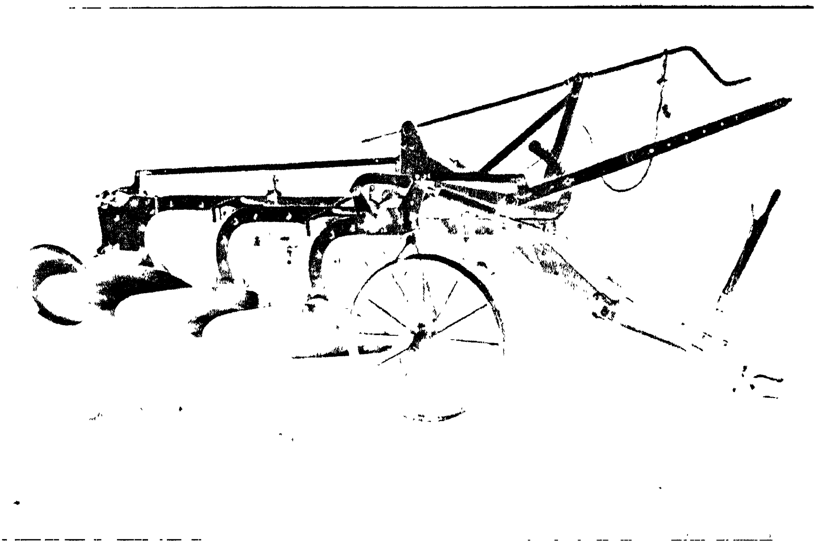
The Placement of Fertilizers.—There is abundant evidence that the effectiveness of a fertilizer depends on how it is placed in the soil in relation to the crop plants. If fertilizers are spread uniformly over the surface and the crop is grown in rows fairly wide apart, it may be quite late in the season before the crop roots can reach part of the fertilized ground. Meanwhile, nutrients may be utilized by weeds and there is a risk of the nitrates being leached away. A further difficulty is that phosphoric acid and potash may be held so firmly by the soil that, when applied in top dressings, they may remain above the normal root zone of the crop and prove quite ineffective. Finally, when a dressing of phosphate is intimately mixed with the whole mass of soil a large proportion is fixed in unavailable form. Potash may be similarly fixed, though rarely to the same extent. There is less fixation if the fertilizer is placed in pockets or narrow bands.

Since the various nutrients present different problems it is well to discuss each separately and then to consider how best to apply mixed or general fertilizers.

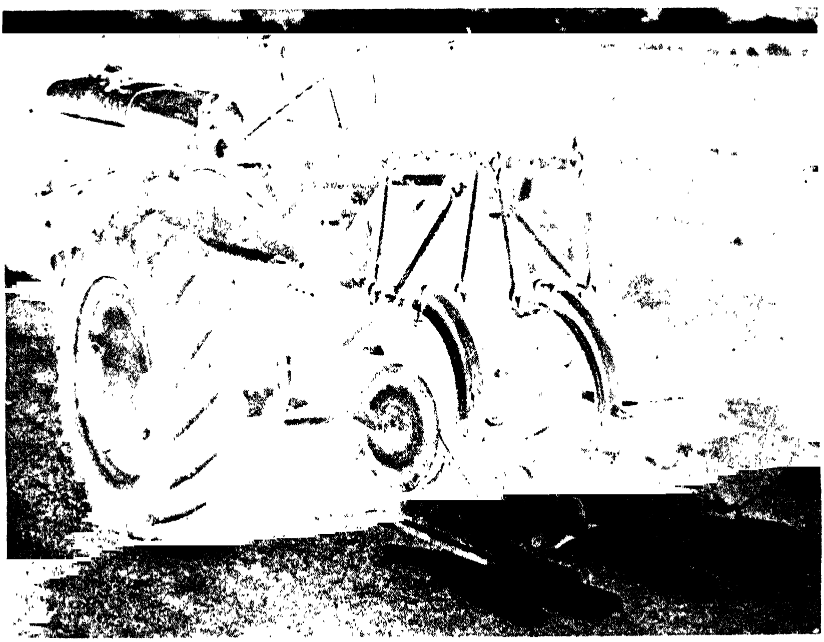
The chief problem in the case of phosphates is, as already said, that of fixation, *i.e.* the formation, with the sesquioxides and clay minerals, of highly insoluble compounds. The extent of these reactions may be indicated by the fact that, even in the case of

extremely phosphate-deficient soils, it is unusual for more than a quarter of the phosphate applied to be recovered in the three or four crops following the application. In some cases the recovery drops as low as 10 or 15 per cent. An obvious method of reducing fixation is to avoid mixing the phosphate with the general body of the soil, or at least to delay such admixture for as long as possible. This can be done by sowing the fertilizer in narrow bands within the root range of the plant. Another consideration is that all plants, if they are to make full growth, must have an abundant supply of phosphate while they are still in the seedling stage. This suggests that the bands of phosphate should be near the seed. Thirdly, no phosphate fertilizers are so highly soluble as to produce solutions concentrated enough to damage seedlings unless, indeed, large amounts of soluble compounds are used; thus there is no objection to a placement in close proximity to (or even in contact with) the seed. Normal dressings can be applied to cereals in this way and smaller amounts to roots, clover, etc. Fourthly, superphosphate, which is the commonest fertilizer in the phosphate group, has some value as a deterrent against wireworm and possibly other insect pests. The simplest way of producing the desired placement in the case of corn crops is to mix a granular form of phosphate with the seed or to use a combine drill which delivers seed and fertilizer into the ground together. Experiments have shown a marked advantage in favour of this method as compared with the older one of broadcasting the superphosphate and harrowing it into the soil. The average of all trials in which there was a clear response to phosphate was that 1½ cwt. applied by the combine drill was as effective as 3 cwt. broadcast. Controlled experiments have not yet been carried out in this country with other crops, though observations indicate the same kind of results with drilled grass and clover mixtures. In this connection it is worthy of note that the earliest form of phosphate fertilizer was roughly broken bones, and that applications in this form produced much longer-lasting responses than dressings of modern materials dispersed through and intimately mixed with the soil.

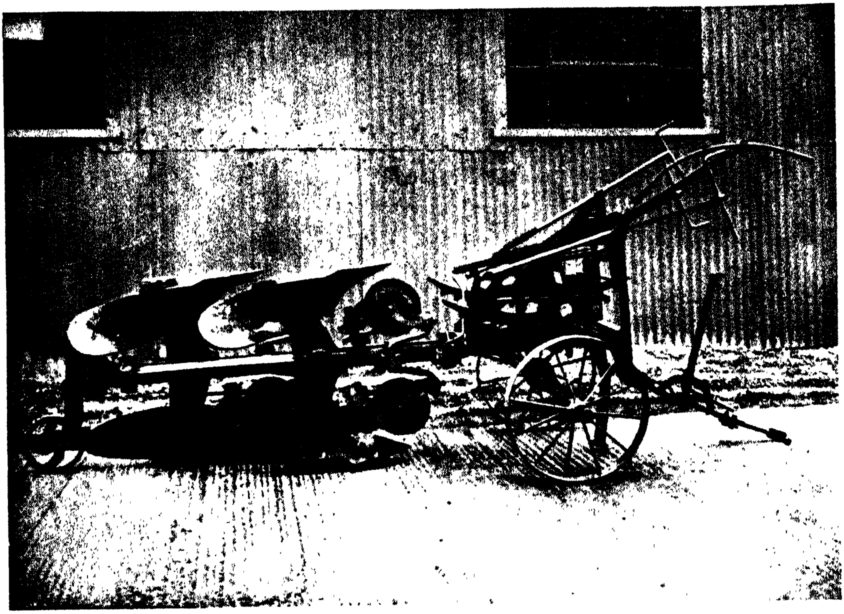
Potassium compounds readily enter into combination with the clay minerals and in some cases—notably in soils overlying chalk—are fixed in unavailable forms. On the other hand, where the soil has a very small amount of colloidal material (*i.e.* is very sandy), losses of potash by leaching are not negligible. Moreover,



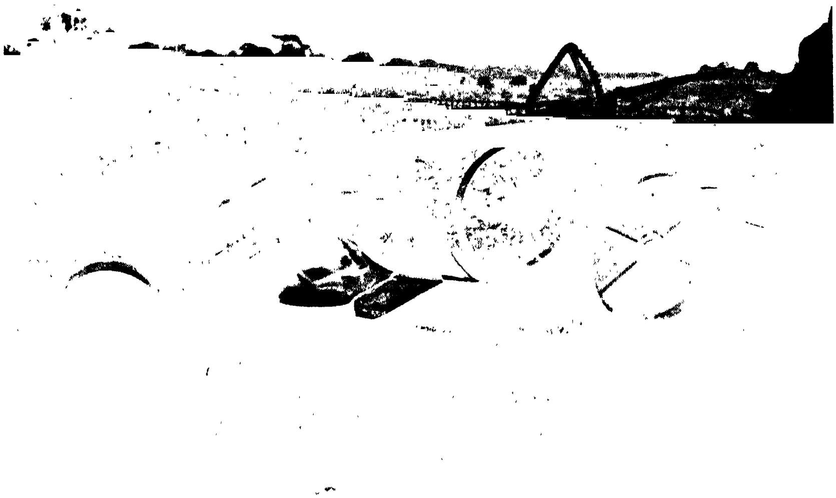
A. THREE-FURROW TRACTOR PLOUGH (RANSOMES)



B. MOUNTED ONE-WAY PLOUGH (ALLIS CHALMERS)



A. Two-furrow "Turnabout" Plough (Bawden)



B. "Grub-breaker" Plough (Massey Harris)

in most cases there is a downward movement of potash from the soil to the subsoil, faster or slower according to the soil's clay-content. It would thus appear that no one type of placement can be ideal for all soils. On the one hand, a surface application to a heavy soil may fail to penetrate to the zone of plant roots soon enough to be of benefit to the crop; experiments with surface applications to apple orchards on heavy land have, in fact, shown that the response may be delayed for several years. On the other hand, potash ploughed into a light soil, if it is neither used by the first crop nor brought up again by still deeper ploughing, may in effect be lost. There is one other consideration, viz., that all potash salts are highly soluble so that there is a risk of damage to seedlings, by over-concentration of the soil solution, if large amounts of potash fertilizer are placed near the seed. This danger will, of course, be greatest under dry conditions. Impure potash fertilizers such as Kainit and " potash salts " are (partly because they must be used in larger quantities and partly because of their content of common salt) much more likely to cause damage than the purer forms. Experience shows that it is safe to apply moderate quantities of the purer forms of potash, in direct contact with the seed of both autumn- and spring-sown cereals, provided that the soil is reasonably moist at the time of sowing. If the soil is very dry germination may be delayed, or the germinating seed may be killed. Damage may be done to potato sprouts when large amounts of potash salts are sown in the drills.

It has been pointed out that nitrate of soda, nitrate of lime, and nitro-chalk should normally be used as top dressings to established crops. This is because nitrates are very readily washed through the soil and lost. In the case of widely spaced plants like cabbage and brussels sprouts in their early stages (*i.e.* before the roots have spread through the soil) there is considerable economy in putting a pinch of any of these fertilizers near each individual plant rather than broadcasting over the surface.

The ammonium radicle is firmly held by the soil but in growing weather nitrification is rapid, and the resulting nitrate rapidly diffuses through the soil. Clearly, then, the effect of placement of the common nitrogen fertilizers must be very short-lived. But in the case of crops sown in rows the plants will get more benefit, and the weeds less, if the fertilizer is placed near the lines of plants. Sulphate of ammonia, like the salts of potash, is highly

soluble and equally liable to cause damage to seedlings, or to the sprouts of potatoes, if it is applied in the immediate neighbourhood of the plants and if the soil is dry. Compound and concentrated fertilizers containing ammonium salts can be safely applied, in reasonable amounts, along with the seed of cereals if the soil is fairly moist. This method is inapplicable in the case of roots and sugar-beet, partly because the seedlings are more susceptible to damage, partly because the normal dressing gives a much higher amount of fertilizer per foot of drill. Placement is beneficial in the case of peas, but the fertilizer must be placed out of direct contact with the seed, and a special type of drill is required to achieve this. In the case of potatoes, satisfactory results are obtained by broadcasting the fertilizer over the ridges before planting. This method gives much better results than broadcasting before setting ridges.

To sum up, we may say that phosphates, when used alone, should if possible be sown either with the seed or in narrow bands near the seed. Compound or concentrated general fertilizers may be sown with cereal seed, though the amount must be restricted if the soil is dry. The same remark may probably apply to drilled grass and clover seeds, though the amounts must be smaller. In the case of other crops grown from seed, the fertilizer must not be in actual contact with the seed, but should preferably be placed close to the latter—*e.g.* in bands 2 or 3 in. on either side and 1 or 2 in. below.

(See also drills, potato planter, potato manuring, sugar-beet manuring.)

RESIDUAL VALUES OF MANURES AND FERTILIZERS

The residual values of fertilizers and feeding stuffs have to be taken into account when compensating an outgoing tenant for improvements. In the case of fertilizers it is recommended that these values should be determined from their actual content of plant nutrients and the costs of the nutrients in the three principal fertilizers, sulphate of ammonia, superphosphate, and muriate of potash. Thus if sulphate of ammonia, containing 20·6 per cent. N, costs £16. 5s. per ton, the value of a unit of nitrogen (1 per cent. of a ton) is $\frac{£16.\ 5s.}{20{\cdot}6}$ = 15s. 8d., or, as a round figure, 16s. In the same way the value of a unit of P_2O_5 contained in 18 per

cent. superphosphate at £12. 10s. per ton$=\frac{£12.\ 10s.}{18}=14s.$, and a unit of K_2O, when 50 per cent. muriate of potash sells at £18 per ton$=\frac{£18}{50}=7s.\ 2d.$, or, as a round figure, 7s.

But when dealing with the residual values of fertilizers applied during the last year of a tenancy, account must be taken of the duration of the effects, for while some nutrients will be completely exhausted in a single season others, according to their form, may become so slowly available that their beneficial action extends over two or more years. Allowances for these differences in availability are made as follows :—

Inorganic nitrogen fertilizers such as sulphate of ammonia, nitrate of soda, etc., and dried blood: No allowance after one crop.

Organic nitrogen in animal and vegetable residues such as bones, hoofs, meat and bone meal, cake meal, etc.: Allow one-half the manurial value after one growing season and one-quarter after two.

Phosphoric acid soluble in water, or (in basic slag) in standard citric acid solution: Allow two-thirds the value after one growing season, one-third after two, and one-sixth after three.

Phosphoric acid in bone products (other than dissolved bones): Allow one-half, one-quarter, and one-eighth the value after one, two, and three growing seasons respectively.

Phosphoric acid insoluble in water or citric acid solution: Allow one-third of the value after one crop, one-sixth after two, and one-twelfth after three crops.

Potash in potash fertilizers: Allow one-half the value after one growing season and one-quarter after two.

To take an example, suppose a ton of compound fertilizer, analysis 7·2 per cent. N, 9·5 per cent. total P_2O_5, 8·5 per cent. soluble P_2O_5, and 9 per cent. K_2O, was applied to potatoes in the last year of a tenancy. The value of the residue to the landlord or incoming tenant will be :—

Inorganic nitrogen . . .	7·2 per cent.—no residue.	
Soluble phosphoric acid . .	8·5 per cent. × 14s. × $\frac{2}{3}$ =	79s. od.
Insoluble phosphoric acid . .	1 per cent. × 9s. × $\frac{1}{3}$ =	3s. od.
Potash	9 per cent. × 7s. × $\frac{1}{2}$ =	31s. od.
	Residual value after one season =	113s. od.

In the case of lime, compensation should be estimated on an eight-year principle, that is, one-eighth of the cost should be subtracted each year after application.

It is also necessary to value the nitrogen, phosphoric acid, and potash in the residues of feeding stuffs purchased during the last years of a tenancy.

If no losses took place between feeding the cakes and meals and applying the manure, the valuation could be made in just the same way as for fertilizers. With foods, however, stock remove varying amounts of nitrogen and phosphoric acid for growth and milk production, and what remains in the dung is subject to further loss according to how the manure is handled; indeed where the urine is wasted and the solids are subject to excessive fermentation and exposure, very little potash and available nitrogen may be left. Nevertheless under average conditions, as where the feeding stuffs are given to dairy cattle in cow houses and to other stock in open yards, where the urine is conserved, the dung well made, and both used effectively, the accepted values of units of nitrogen, phosphoric acid, and potash in the food are 30, 50, and 60 per cent. respectively of their unit prices in fertilizers. These fractions should be halved after one crop.

For example, if a ton of earthnut cake contains 7·6 per cent. nitrogen, 2·0 per cent. phosphoric acid, and 1·5 per cent. potash, and the unit prices are the same as in the previous section, the manurial value of the cake will be as follows:—

7·6 units of N	× 16s. per unit	× by the fraction	·3	=	36s. 6d.
2·0 ,, P_2O_5	× 14s. ,,	× ,, ,,	·5	=	14s. 0d.
1·5 ,, K_2O	× 7s. ,,	× ,, ,,	·6	=	6s. 4d.
	Average value of residue			=	56s. 10d.
	Average value after one crop			=	28s. 5d.

While the above valuation applies to average circumstances, adjustments must be made for abnormal cases. Thus one-third might be deducted if the manure is derived from cows in open yards and even two-thirds—reducing the figure to about 19s.—where conditions are highly unsatisfactory. On the other hand, when dealing with classes of stock such as fattening cattle, which remove less plant nutrients from their food, the valuation of the residue might be increased by one-third; but even here deductions would have to be made if the handling was unsatisfactory.

There are tables available to those who wish to ascertain the nitrogen, phosphoric acid, and potash content of the common

feeding stuffs, but with compound cakes and meals the only key to manurial value is the declared percentage of protein (albuminoids). With nutrients at prices used in the above examples a reasonable estimate of the manurial value of such foods is obtained by allowing 1s. 4d. for each unit of protein and a residual value of 8d. after one crop has been removed. For example, a compound cake containing 18 per cent. protein has a manurial value of 18 × 1s. 4d. = 24s., or 12s. after one crop.

When straw is brought on to a farm and finds its way into the dung its combined manurial and mechanical value may be rated at 12s. a ton, or 6s. after one crop has been removed.

The above methods of evaluation provide a suitable basis for determining compensation, but no formula can deal with every possible contingency, and in the last resort the valuer must use his own judgment.

LIME

The practice of adding lime to the soil is very ancient. Chemical methods have been devised for measuring the hydrogen ion concentration and the "lime-requirement" (see pp. 28-29) of soils, and although such estimations are valuable they cannot be used as an absolute guide. They must be taken in conjunction with evidence afforded by the herbage that the soil is producing. A shortage of lime is indicated by the accumulation and slow decay of organic matter, often forming thick springy turfs of unrotted plant debris, by the presence of exceptionally high proportions of certain weeds such as sorrel, spurrey, and yellow corn marigold, and by the failure of crops like red clover, barley, and sugar-beet. Another point is that there are very few earthworms in acid soil.

Calcium is, of course, an essential plant nutrient, but lime—*i.e.* calcium carbonate—has highly important secondary effects upon the soil and upon the growth of plants. It improves the texture of the soil by flocculating the clay particles and is particularly beneficial to heavy land. It is the most important base in the soil and it determines the soil's reaction; it has to be employed to counteract the acidity produced by such fertilizers as sulphate of ammonia. The presence of lime is necessary for nitrification, nitrogen fixation, and other bacterial activities, and it checks the fungus that produces finger-and-toe disease. Liming old ploughed-up grassland leads to the liberation of a useful supply of nitrogen and perhaps a little phosphoric acid that has been locked up in

plant remains. Liming acid land also reduces the tendency for the phosphoric acid of fertilizers to be fixed quickly in an unavailable form. On the other hand, liming may throw out of solution some of the " trace " elements, particularly manganese and boron, thereby creating a deficiency.

Shell Lime.—Shell lime is prepared by heating limestone rock to a temperature which reduces the calcium carbonate to calcium oxide or quicklime with the liberation of carbonic acid gas. Its exact composition depends on the purity of the rock, which may be almost pure calcium carbonate. Quicklime is hygroscopic and also takes up carbonic acid from the air. Thus unless the quicklime is freshly prepared it is liable to contain a portion of hydroxide and carbonate.

It is usual to apply shell lime at the rate of about 2 tons to the acre. Smaller quantities are difficult to distribute evenly. The usual method of application is to cart the lime out to the fields after the autumn ploughing has been completed and to deposit it in small heaps at regular intervals. Rain and contact with the atmosphere soon cause the heaps to swell and crumble, and the lime is " slaked " or changed to calcium hydroxide. When the lumps are completely pulverized the lime is scattered over the ground with shovels, and that portion which is not washed into the soil by the winter rains is worked into the ground by the spring cultivations. The lime is at first caustic in effect and should not be applied to grassland and growing crops, but in the form of hydroxide it is washed into the soil and well distributed and, though it finally reverts to the form of carbonate by absorbing carbonic acid, it is in such a fine state of division that it is usually more immediate in action than is coarsely ground limestone. Sometimes, however, it is desirable to apply this form of lime to grassland. In such cases it becomes necessary to slake the quicklime thoroughly if " scorching " the grass is to be avoided. Slaking is best effected by carting the lime into a large heap some considerable time before it is to be applied and allowing it to slake slowly by absorbing moisture from the air; but in dry periods the action may be hurried on by the application of water.

Many limestones which are burned for agricultural purposes contain more than 50 per cent. of magnesium carbonate. Under most conditions magnesian lime produces good results, but an excess of magnesia in light soils may be harmful.

Ground Lime.—This is prepared by grinding shell lime to a

fine powder. Its action is similar to that of lump lime, but its fine state of division renders it easy of distribution by an ordinary manure-spreading machine, and small quantities produce as much temporary improvement as large dressings of unground material. Some farmers apply ground lime once every four to six years in dressings of 10 cwt. per acre. It has to be used soon after delivery, for it soon swells and bursts the bags.

Ground Limestone.—This is prepared by grinding the naturally occurring rock to a fine powder. It may be slow to act if it is not finely ground and uniformly distributed throughout the soil, but when ground to pass through a sieve with 100 meshes to the inch it has been found to be as effective in sour soil as an equivalent amount of burnt lime. When over 30 per cent. passes this sieve it is fine enough for ordinary purposes. Since $1\frac{3}{4}$ tons of ground limestone are equivalent in effect to 1 ton of shell lime, it is more costly than the latter to cart and spread. Its advantages as compared with burnt lime are that it can be kept indefinitely without deterioration, that it is much more pleasant to handle, and that its use in quantity has no damaging effect on crops; it is also, in many localities, cheaper than burnt or hydrated lime, not only weight for weight but also unit for unit, counting in terms of calcium oxide.

Chalk.—Chalk, where it occurs naturally and can be obtained cheaply, may be applied to the soil instead of lime. Some types are difficult to grind and these are usually applied in heavy dressings of about 4 or 5 tons per acre at long intervals; but ground chalk can be got in some districts and small lump chalk in others. However, some types of chalk, if left in heaps over winter, crumble so much as to be easily spreadable.

Waste Limes.—Waste limes, usually in the form of finely divided and rather wet calcium carbonate, are sometimes obtainable from sugar factories, paper mills, etc. They may be used for agricultural purposes in place of ground limestone, but they are often so wet and pasty that they are difficult to spread; as they sometimes contain injurious substances it is best to try them first on a small scale.

It is now the common practice to employ contractors for liming. A special type of equipment is used which collects its load at the works and distributes the material over the field.

Marl and shell sand are other calcium-rich substances cheaply obtainable in some places.

CHAPTER V

IMPLEMENTS AND CULTIVATION

PLOUGHS AND THEIR CONSTRUCTION

THE earliest form of plough was simply an enlarged hoe which stirred the soil as it was dragged along. This type of implement, which may be regarded as a single-tined cultivator, is still widely used in India and other Eastern countries. A crude mould-board plough came into use in Europe in pre-Roman times, but it was not until the eighteenth century that ploughs approaching the modern type were invented.

The Single-furrow Plough.—Modern ploughs vary considerably in detailed construction but all are built on the general principles shown in Fig. 2. The essential features are the beam, the plough body, and the coulter. The plough body consists of a frame, sometimes called the "frog," to which are attached the share, mould-board, slade, and the side cap, "cheek" or land-slide. The coulter makes the vertical cut in the soil; the share makes the horizontal cut; the mould-board or breast moves the soil sideways and at the same time inverts it; the side cap receives the side thrust due to the turning of the furrow-slice; and the slade takes the weight of the plough and of the furrow-slice. The horizontal cut is not the full width of the furrow-slice, for enough soil must be left uncut to steady the slice so that the mould-board may invert it and not merely push it into the open furrow.

The draft of the plough is due to the resistance of the earth to the two cutting edges, the energy required to lift the soil and invert it, and lastly, the friction of the plough parts against the soil surfaces. If the plough is properly hitched there will be little or no friction against the side cap, the pressure on the slade will largely depend on the weight of soil resting on the mould-board, and most of the friction will be due to the size and length of the breast. In all cases friction is greatly reduced when the plough surfaces are highly polished.

The Mould-board or Breast.—The mould-board may be made of cast-iron, but in most modern ploughs it is constructed

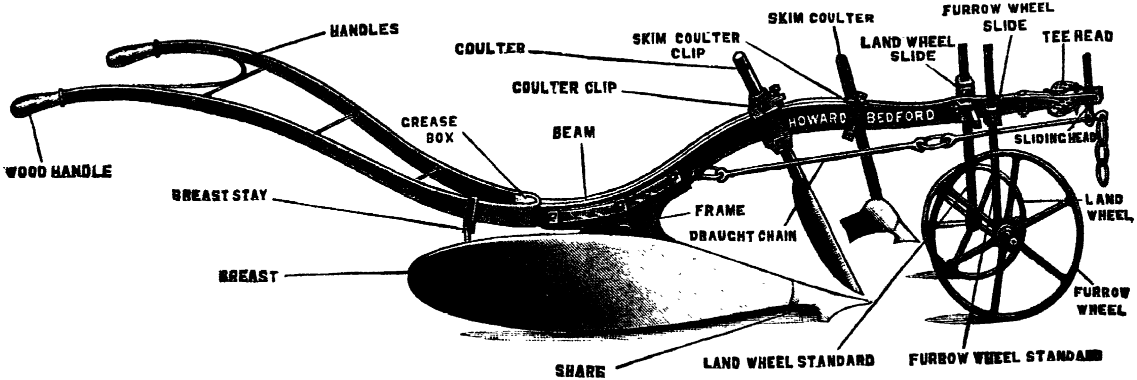


FIG. 2.—Wheeled Lea Plough (Howard)

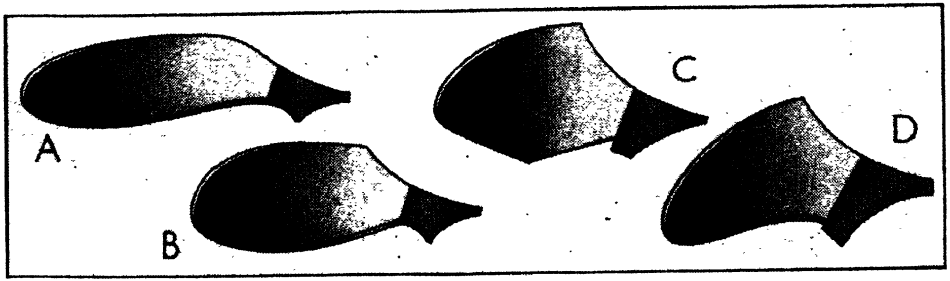


FIG. 3.—Plough Breasts

A, Lea; *B*, General Purpose; *C*, Semi-digger; *D*, Digger

of soft-centred or soft-backed steel. A steel breast has a wearing surface of high-carbon metal which is extremely hard and takes on such a high polish that the draught is minimized. High-carbon steel alone, however, is too brittle to be satisfactory, and has to be backed with low-carbon metal which is tough and strong and resistant to fracture. For average conditions and for soils which are more or less free from sharp and hard grit, steel mould-boards scour better than other types, but they do not wear as well as chilled cast-iron.

The four main types of plough body, in the order of decreasing length and increasing depth of mould-board, are: lea, general purpose, semi-digger, and digger (see Fig. 3). The lea and general-purpose bodies have a mould-board with a very gradual curve and a slightly convex surface; the digger body mould-board is short and abrupt with a pronounced concave surface; and the semi-digger is intermediate between the full digger and general purpose, the mould-board having a slightly concave surface. These differences in length and curvature determine the degree of pulverization of the soil and the relationship between furrow width and depth. The lea and general-purpose bodies are suitable for shallow ploughing only, the maximum depth being about two-thirds of the furrow width. They turn an unbroken furrow-slice and press each slice firmly against the previous one, thus "setting-up" the furrows so that they are exposed to the full action of the weather. The work of the semi-digger and digger mould-boards differs from the work of the lea and general purpose bodies in that the furrow-slices are not pressed against each other. The soil is caused to rise up the mould-board and fall over in a broken and pulverized condition, the degree of pulverization being greater with the digger body than with the semi-digger, so that the soil is worked into a mould in addition to being inverted. The semi-digger body will plough a furrow slightly more than 2 in. deep for every 3 in. of width; and the digger body will plough a furrow as deep as it is wide, or even deeper. The digger body is therefore essential for deep ploughing. Digging ploughs are used extensively for cross-ploughing land that has been exposed to the action of frost throughout the winter, and for ordinary spring ploughing, because the broken furrow-slice assists greatly in the preparation of the seed-bed. The digger body is not always satisfactory for ploughing grassland, particularly on the heavier types of land, because it does not effectively bury the sod. The

semi-digger body, on the other hand, will deal with almost all types and conditions of soil, and is gradually becoming recognized as the most widely adaptable type, especially for tractor work.

The Share.—Shares are very subject to wear in certain soils. For example, on dry, hard, flinty land a day's ploughing can cause one to be worn to the point of requiring renewal or repair, whereas on soft fen land the same part may last two seasons. Shares for the older types of plough were almost always made of wrought-iron. The outstanding advantage of wrought-iron is the ease with which it can be welded so that, when worn, it can be restored to its proper shape by hammering on another piece of metal. At the present time most shares for horse ploughs and small tractor ploughs are made of chilled cast-iron. Cast-iron cannot be welded or hammered into shape; if sharpening is necessary it has to be done on a grindstone, and when wear has gone too far, renewal of the part becomes necessary. These shares wear well, but their failure to withstand shocks makes them unsuitable for ploughing land containing large stones, especially if the plough is tractor-drawn. Under these conditions cast-steel shares are preferable. Steel shares wear well in land containing little abrasive material. When they lose their edge they may be sharpened by heating, hammering the metal out to the desired shape, and retempering; but this can be done only once or twice, after which replacement becomes necessary. Shares are obtainable which have the bottom layer of metal hardened. When they are in use the cutting edges are maintained by the more rapid wear of the softer upper portions and sharpening is unnecessary.

Bar-point shares have been devised for land that is very hard and stony. The principle of the device is to replace the point of the share with the chisel-pointed end of a long solid bar which can be advanced, turned, or reversed in a few seconds to make good the wear. Some are spring-loaded to absorb the shock caused by hitting fast obstructions. The very advanced point that it is possible to obtain is particularly useful for getting into hard ground. Bar-point shares can be fitted only to those bodies designed to take them.

The Coulter.—The coulter for making the vertical cut in the soil ahead of the plough body is either a knife or a disc. The knife coulter, like the share, may be made of steel or wrought-iron, and has to be sharpened or renewed when it becomes inefficient through wear. It is clamped to the beam of the plough and has a

backward and forward adjustment. The coulter stem may be round so that the blade can be given a " set " towards the land if necessary, or the same object can be achieved with a flat stem by the use of iron wedges. For ordinary work the point of the coulter is set forward so that its leading edge points towards the point of the share and makes an angle of about 35° with the vertical, with the tip of the coulter about 1½ in. from the share. When an absolutely unbroken furrow-slice is required the coulter is advanced considerably. The disc coulter is a freely revolving circular disc with a cutting edge. It is usually carried on a cranked round stalk clamped to the beam of the plough. Raising or lowering the stalk in the clamp increases or decreases the clearance between the disc and the share; moving the clamp along the plough beam varies the position of the disc relative to the share point; and turning the stalk in the clamp adjusts the position of the disc relative to the landslide of the body. The correct setting of a disc coulter is determined by the conditions under which it has to work, but three general rules can be laid down. Firstly, it must not be too deep. On hard ground a deep coulter takes some of the weight of the plough, prevents penetration, and causes excessive wear on the coulter bearings. It should be set just deep enough to leave a clean furrow wall. Secondly, it should run slightly to the land side of the plough body. Too little clearance between the disc and the side cap produces a broken furrow wall, and too much clearance gives the work a poor appearance and may allow the plough to crab. Thirdly, for normal work the coulter should be set over the point of the share; but in hard ground it should be moved back behind the point to assist penetration. The plain disc coulter is not suitable for ploughing-in long material such as straw left by the combine harvester. The straw, being so tough that the coulter cannot cut through it, collects in front of the coulter and prevents it from revolving. This trouble is largely overcome if the edge of the disc is wavy: the wavy edge keeps the disc turning.

The skim coulter is used in addition to the knife or disc coulter for ploughing in herbage and dung. It skims off that corner of the furrow-slice against the ordinary coulter and thereby prevents any vegetation from protruding between the turned furrow-slices. A skim coulter should be set sufficiently far forward on the plough beam to allow it to pare off the shoulder of the furrow before the furrow is lifted; it should throw the paring into the furrow

bottom; and it should not be set too deep. When used in conjunction with a disc coulter the point of the skim is set close to the disc so that surface vegetation and small stones cannot wedge between the two. Skims cannot always be set to do good work on rough ground because of the considerable variations in their depth of working. Under these conditions surface vegetation can be buried satisfactorily if the disc coulter is tilted so that the top of the disc leans towards the ploughed land.

Multiple Ploughs.—Double-furrow gang ploughs on light land can be drawn by three good horses. On average soil four horses are needed, and to obviate side draught it is best to have them hitched one pair behind the other. In the new countries of the world multiple ploughs are employed on all but the smallest farms, for in this way manual labour per acre is reduced and horse labour is not increased.

The multiple ploughs in common use in this country are constructed for tractors and turn from two to six furrows at once. A three-furrow model is shown in Plate I, *A*. The plough bodies and their associated coulters are attached to two or more parallel beams and spaced so that each in turn inverts its furrow-slice into the preceding furrow. The distance apart of the beams, which determines the furrow width, may be adjustable. The bodies are built on the same lines as the body of a single-furrow horse plough; but the bodies, except the rear one, have no slades and either very reduced side caps or none at all. Provision is usually made for adjusting the pitch of the individual bodies. The plough is carried on land and furrow wheels in front, with generally a small wheel at the rear running in the open furrow. The land and furrow wheels are on cranked axles through which, by means of screws, or by levers working in quadrants, the depth of ploughing is controlled and the plough is kept level. The rear wheel may or may not be adjustable for height. The hitch, which is flexible in a vertical direction and rigid horizontally, usually consists of three members: the hake-bar attached to the beams, a draw-bar running forward from the hake-bar to the tractor, and a cross-piece between the hake-bar and the draw-bar. The three members thus form a triangle. A wide range of adjustment is provided in the hitch so that the draw-bar never slopes downwards from the plough to the tractor and so that the line of draught of the plough is brought as near as possible in line with the centre of power. A lever and quadrant or a screw adjustment is often

incorporated in the hitch to enable the plough to be moved towards or away from the land and thereby increase or decrease the width of the front furrow.

Tractor ploughs are subjected to much greater shocks than horse ploughs, because, unlike the horse, the tractor does not stop when the plough hits an obstruction, and to prevent damage to the plough a safety device such as a wooden shear peg or a spring-loaded draw-hook is put in the draw-bar. All conventional tractor ploughs have a self-lift actuated by the cleated land wheel. The lift is either of the rack and pinion type, the pinion being attached to the wheel, or of the drum type, incorporating a clutch. A pull on a cord brings the rack down on to the pinion or engages the clutch, and as the land wheels rotate the cranked axles raise the plough out of the ground. When the plough is lifted completely the rack flies away from the pinion and the clutch disengages. A second pull on the cord drops the plough into work. On the larger tractor ploughs the self-lift also causes the rear portion of the plough frame to move up the pillar carrying the rear wheel.

Some tractor ploughs can be reduced in size by removing a body. For instance, a three-furrow plough can be converted to a two-furrow by removing the centre body and putting the rear body forward into its position.

The cost of ploughing an acre is increased if a tractor capable of pulling a six-furrow plough is used with a smaller plough. It is therefore desirable to give a tractor the largest plough it can pull. In practice, however, a very wide plough cannot do good work on rough land on which one furrow is liable to be too deep while another is too shallow. On rough surfaces it may be better to hitch two of the smaller multiple ploughs together, the larger plough being placed in front of the smaller, and so secure a measure of flexibility rather than attempt to operate a single implement carrying the same total number of bodies.

Mounted Ploughs.—There has been a marked tendency in recent years to mount a wide range of cultivating tools on the tractor rather than to trail them behind, the object being to make the outfit more manœuvrable and to simplify the construction of the implements. The method of attaching the implement to the tractor is important. Unless the implement can be put on and taken off the tractor quickly and easily, much time may be lost in changing from one job to another. The "three-point suspension" method enables one man to couple a tractor to a mounted plough

just as quickly as to a conventional trailer plough. Mounted ploughs, which may be capable of ploughing up to three furrows, are raised and lowered on the power-lift of the tractor. Generally the depth of ploughing is controlled by adjustable land wheels, but with the Ferguson system the hydraulic lift on the tractor is also used to control depth. At any given setting of the lever operating the lift the draught of the plough remains constant. On uniform ground the ploughing depth does not vary, but if the plough passes from soft to hard ground it will be raised unless the lift lever is adjusted to permit the draught of the plough to increase. An experienced operator, by careful manipulation of the lift lever, can plough at a uniform depth even in variable land.

" One-way " Ploughs.—Ploughs of this type are constructed with the object of enabling the plough to work backwards and forwards, turning all the furrow-slices in one direction. With one-way ploughing marking-out is not necessary, there are no ridges or finishes, idle travel on the headland is reduced to a minimum, and land can be ploughed as it is cleared—a great help when land is being folded with sheep or when strips of land in a field are cleared at different times, as often occurs in market gardening. One-way ploughs have right- and left-hand bodies arranged so that it is possible to change from one to the other on the headland. The various one-way ploughs differ from each other in the method of mounting the bodies and in the method of effecting the change-over. The single-furrow balance plough has two beams shaped like a flat V and balanced about a pair of wheels placed at the point of the V. One beam carries the right-hand body and the other the left-hand. The plough is not turned on the headland. When one body is lifted out of the ground the other falls into work. The turnabout plough has the right- and left-hand bodies mounted opposite each other on the same beam. When the plough is turned on the headland the beam rotates through 180° and brings the other set of bodies into the working position. The turn-wrest plough has a single body with a double mould-board and double share, and a double coulter. When the plough is turned on the headland the body is swung from one side to the other thus enabling each mould-board and share to be used in turn. A one-way tractor plough is illustrated in Plate II, *A*. The two bodies on the mounted one-way plough in Plate I, *B*, are independent of each other. When one is in work the other is raised out of the ground.

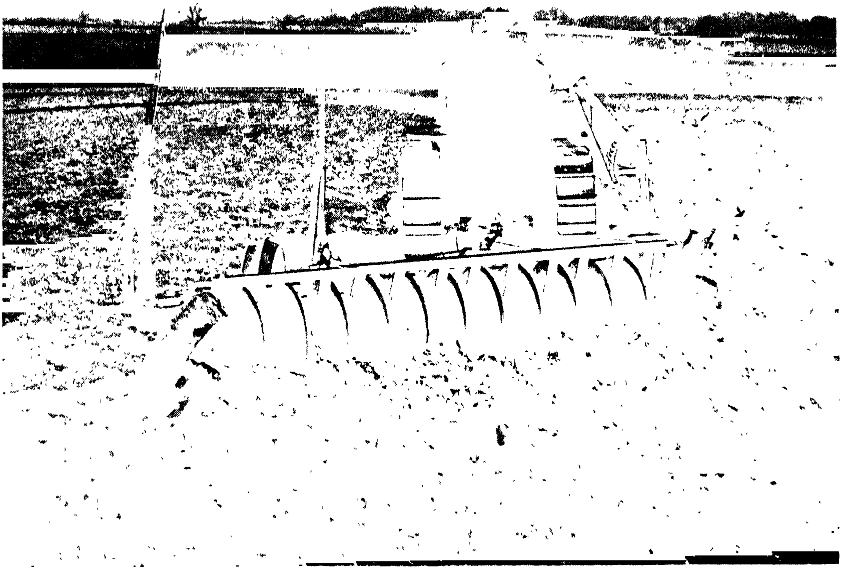
Special Ploughs.—Deep digging ploughs are used for ploughing up to 16 to 18 in. deep. The frame of the plough is very heavy and the distance between the point of the share and the beam is much greater than with the more usual type of plough. They are usually of the trailer type but the Wilmot "Turnall" is bolted direct to the tractor and has only a rear wheel, the depth being controlled by varying the pitch on the share. An ordinary wheeled tractor can pull a single-furrow deep digging plough; a track-laying tractor is necessary for the larger sizes.

The "Grub Breaker" plough (Plate II, *B*) has been used in the reclamation of derelict land. It can plough a flat furrow up to 26 in. wide and 12 to 16 in. deep; and the knife coulter placed against the share point enables it to work in rocky land. Another type of plough which can be used on rough land containing tree roots and rocks is the Australian Stump Jump. The bodies on this are mounted so that when one meets an obstacle it rises over it and then falls back into work.

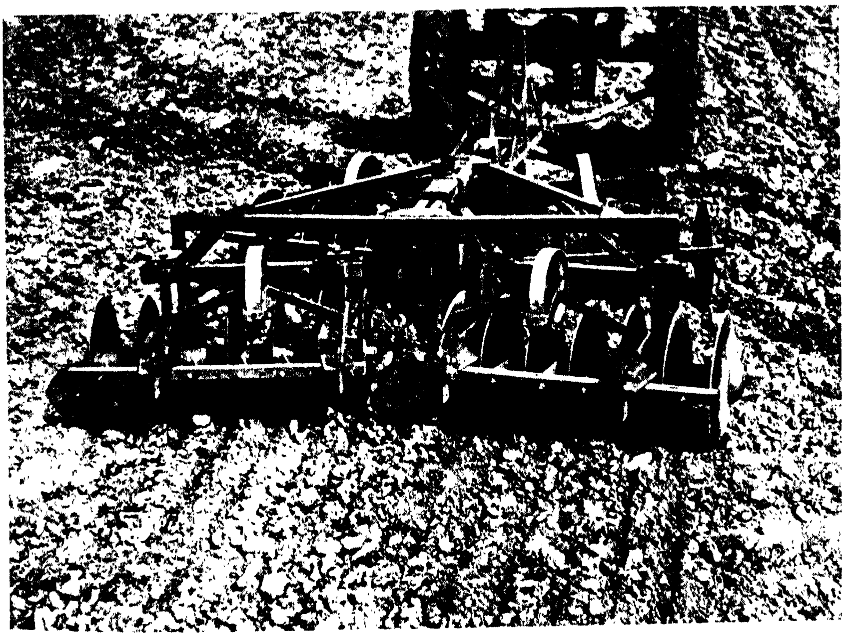
Disc Ploughs.—These implements are used to some extent for tractor ploughing. They work on a different principle, employing rotating discs to cut and turn the furrows. The discs are 24 to 28 in. in diameter and usually four or five in number; they are mounted on stub beams which are clamped to the heavy main beam of the plough and the spacing for width of cut is adjustable. The discs are fitted with scrapers which keep them free from sticky soil. Some of the advantages of disc ploughs are: they can be used on hard soils where mould-board ploughs cannot penetrate and will not scour; their rolling action prevents breakages where the soil contains large stones, stumps, or tree roots, and, moreover, reduces the wear on the working parts. On the other hand, under average conditions, mould-board ploughs pulverize the soil better, leave fewer clods, and cover surface growth and rubbish more completely. Stump-jump disc ploughs are also made.

Disc implements known as harrow-ploughs, one-way discs, or polydiscs (Plate III, *A*), are made to perform operations intermediate in character between the work of disc ploughs and that of disc harrows. A seed-box is sometimes attached to the polydisc so that cultivating and seeding can be done in one operation.

The Subsoiler.—Subsoiling consists of stirring up the soil to a greater depth than is reached by ordinary ploughing. It differs from deep ploughing in that it does not bring the subsoil to the surface but leaves it broken and aerated *in situ*. Subsoiling



A. Polydisc Plough



B. Tandem Disc Harrow (Steel)

PLATE IV

1. High-cut Crested Furrows

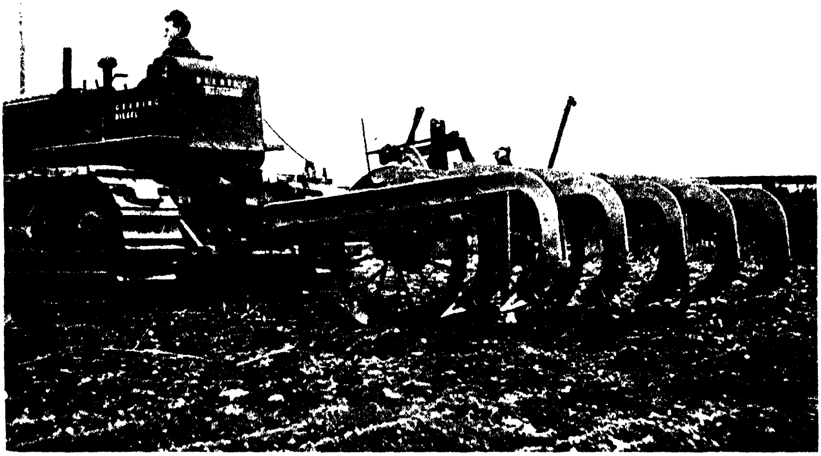
2. Rectangular Furrows

3. Broken Furrows

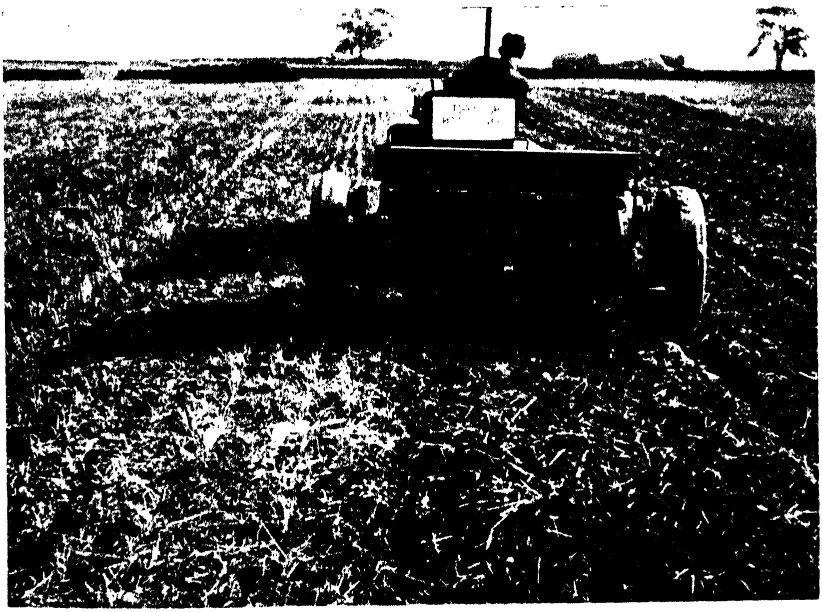
4. Inverted Fu

STYLES OF PLOUGHING.

Farmer and Stockbreeder

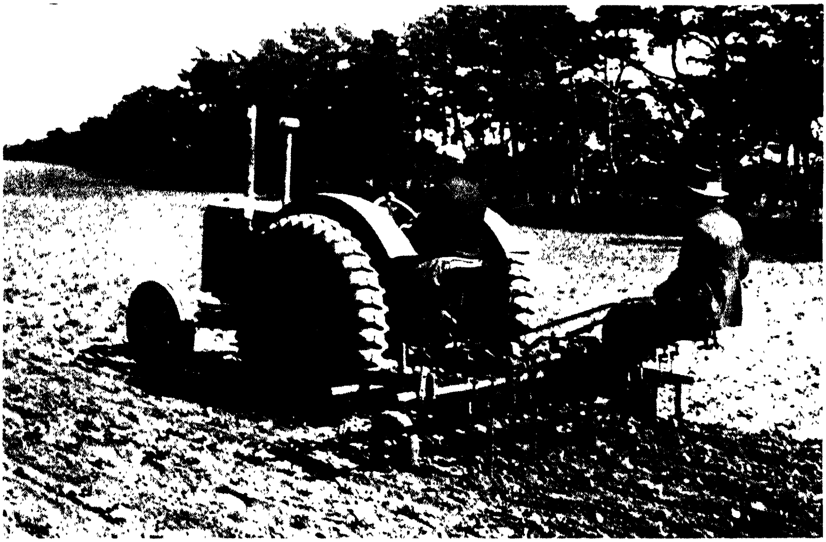


A. Heavy Tractor Cultivator (Ransomes)



B. Rotary Cultivator (Fishleigh)

PLATE VI



A. Steerage Tractor-hoe (Miller)

B. Row-crop Tractor with Rear-mounted Hoes

is adopted in preference to deep ploughing where it is undesirable to bring the subsoil to the surface. Subsoiling is absolutely necessary where a plough-pan has been formed or where an iron-pan has been developed by a precipitation of iron salts a few inches below the surface. Even on ordinary soils it may be advisable to practise subsoiling in preparation for tap-rooted crops like sugar-beet, carrots, and parsnips.

The essential feature of a subsoiler is a large digging tine strong enough to break up the soil below ploughing depth. The horse-drawn subsoiler follows an ordinary plough and tears up the bottom of the open furrow. The digging tine may replace the front body of a two-furrow plough ; on some heavy tractor ploughs a tine may be fixed behind each body. The special tractor subsoiler is a two-wheeled stoutly constructed frame to which the subsoiling tine is attached. A self-lift raises the implement out of work.

Ridging and Potato Ploughs.—The horse-drawn ridging plough is similar to the conventional plough except that the two wheels supporting the front of the beam are of equal size, coulters are absent, and the plough body is replaced by a ridging body. The ridging body is of the double mould-board type with a renewable point instead of a share. Ridging ploughs are used in conjunction with a marker to form ridges for root crops, and also for earthing up potatoes. The marker is set according to the row width and makes a mark on the land down which the point of the ridging body is driven on the return bout. Each time the plough is turned on the headland the marker is swung from one side to the other. Substitution of a potato-raising body for the ridging body converts the ridging plough into a potato lifter. The lifting body has a broad, flat share behind which is a series of prongs which slope upwards and outwards. The share is pulled beneath the row and as the whole body of the ridge passes over the prongs partial separation of potatoes from soil is effected. Some of the potatoes may be buried and picking may be difficult, but the potato plough is probably less damaging to the tubers than any other form of lifter. Ridging bodies and potato ploughs can be attached to tractor tool-bars. Three ridging bodies or one or two lifting ploughs are usual. If there is only a single plough it is often attached to one end of the tool-bar with a harrow leaf on the other end, so that as the plough is raising one row the last but one row lifted is harrowed. If there are two ploughs they are fixed to the ends of the tool-bar to lift every other row. The tractor

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potato plough is much larger than the horse version, and the extra speed obtainable with the tractor improves the performance of the plough as a lifter.

Beet Ploughs.—Before sugar-beets can be pulled they have to be loosened by special beet-lifting bodies. The bodies are either built into horse-drawn ploughs or are attached to tractor tool-bars. There are two types of body, the single- and double-arm. In the single-arm a flat steel plate carries at its base a small share which runs under the row and loosens the beets. Right- and left-hand single-arm bodies are made so that when they are mounted on a tractor tool-bar they push the loosened rows together in pairs. In the double-arm or bow-legged type, a single-row plough has a share running on each side of the row. This type, which is not often used on tractor tool-bars, loosens the beets but does not displace them.

PLOUGHING

The old style of ploughing in Britain was to invert the soil so that the furrow-slice remained unbroken, whereby the field was laid out in crested furrow-slices. This fashion was established before the advent of the seed-drill, and it leaves the land in a suitable state for the distribution of seed by hand. It is also useful in that it leaves the furrows well exposed to the action of the weather and promotes drainage. About 1885, however, digging ploughs were introduced. These implements turn the furrows over in a completely broken condition, leave the land almost level, and in some cases in a satisfactory condition for drilling. Modern general-purpose ploughs produce a range of styles intermediate between these extreme types.

The most suitable depth of ploughing depends to such an extent on the nature of the soil that no hard-and-fast rules can be laid down in regard to it, and every farmer must determine the most suitable depth for his own land. Deep cultivation creates a deeper root-bed for the crop and, by bringing a greater volume of soil under the influences of weathering and aeration, tends to increase fertility; occasional deep ploughing also improves the drainage of heavy land. An average depth in many districts is about 6 or 7 in., the range being from 4 or 5 in. in the case of spring-sown barley to perhaps 8 or 9 in. in preparation for potatoes or roots. In some limestone regions 5 or 6 in. represents the maximum possible. At the other extreme, on deep stoneless silt

land, occasional ploughing to 15 or 18 in. or sometimes more, is done by tractor ploughs or by steam tackle. No matter what the most suitable depth of ploughing may be, it is advisable to vary it slightly from year to year in order to prevent the consolidation of any particular stratum with the formation of a "pan."

Experiments on the effects of deep ploughing, under the auspices of Rothamsted, have been in progress since 1946. The trials cover a wide variety of soils in various parts of England. In general it can be said that deep ploughing (12 to 15 in.) has in no case done serious harm. It should be noted, however, that extra doses of nitrogen and phosphate have been given to make good the deficiency of the material brought to the surface. This material is usually richer in potash than the former top soil. In a few cases the operation has had a definitely beneficial effect, as measured by crop yields.

Years ago, when broadcasting of corn was common, the furrow width was to a large extent determined by the requirements of the crop to be sown. Nowadays it is exceptional for such considerations to be taken into account and most British ploughs are made to turn furrows up to 10 or 12 in. wide. Large tractor ploughs have even wider furrows than this, and special single-furrow ploughs, *e.g.* the "Grub Breaker," may produce furrows up to 26 in. wide. The furrow width of single-furrow ploughs can be varied easily, but there is a practical limit to the width because a plough cannot invert a furrow that is wider than that for which it is designed; it will simply raise the soil and allow it to fall back again. The furrow width of multiple-furrow tractor ploughs can often be adjusted by varying the distance between the beams. The adjustment is usually in 1-in. steps over a range of 2 in., *e.g.* 10, 11, and 12 in.

Ploughs are constructed to work the land to a given depth and turn over a given breadth of furrow. Any plough cannot be expected to do any kind of work, though it may be adjusted for different purposes within certain limits. Farmers must therefore purchase implements to suit their own particular requirements, ploughs being obtainable for dealing with any type of land.

The first operation in the ploughing of a field is the marking off of the headland, and the second is the marking out of the "lands." Marking-out is usually done by ploughing a shallow single furrow. The multi-furrow plough is tilted by means of the

levelling lever so that when it is put into work only the rear body turns a furrow. The headland is marked off by turning a furrow-slice parallel to the boundaries of the field, usually round the whole field, though for horse-ploughing it may follow three sides only, and in a rectangular field two headlands may suffice. The width of the headland may vary from 5 yds. in horse-ploughing up to 11 yds. with tractor outfits. The " lands " are marked out parallel to one side of the field, generally the longest. This setting-out is done with the aid of sighting poles so that each " land " is of uniform width across the field. " Lands " are necessary in all cases where an ordinary plough is used—they are not necessary with one-way ploughs—in order to save time in turning on the headlands, but they are also useful in acting as guides for the broadcasting of seed and fertilizers, and in some cases for facilitating surface drainage. The size of a " land " in ordinary arable practice is 22, 24, or up to 48 yds., the greater distances being used in tractor work, but on heavy land which tends to be waterlogged they may be of 5 or 6 yds., or in some cases even less, in order to introduce a large number of open furrows which serve as shallow drains.

There are several methods of setting up the ridges around the single shallow furrows marking out the " lands." The simplest ridge is made by taking the plough in the opposite direction to that travelled when marking out and, with all plough bodies in work, overlapping the marking-out furrow-slice with the front furrow-slice. A strip of unturned land remains under the ridge. If it is desirable to invert the whole of the sod this is done by making a split-ridge setting. To do this the plough is set as for marking out, and a second, shallow, single furrow-slice is turned away from the marking-out furrow, leaving a narrow unploughed strip of land between the two furrows. When ploughing lea or grassland this unploughed strip is often removed, a potato spinner being sometimes used for the job, especially with horse ploughing, but in tractor ploughing the tractor wheels destroy the strip. The plough is then set to go to the normal depth, and the double furrow-slices are turned against each other in the ordinary way. An alternative method of split-ridge setting is sometimes adopted with a three-furrow or larger plough. Working on the marking-out furrow, the plough travels in the opposite direction with its front body turning another shallow furrow-slice outwards to complete the split, its second body running light in the open furrow made

by the rear body when turning the first shallow furrow-slice, the third body ploughing a furrow underneath the first split and the remaining bodies ploughing normally. The plough is then turned on the headland and the ridge completed by turning in the second shallow furrow-slice with the front body, the other bodies ploughing normal furrows. Ridges should be kept as flat as possible and the plough brought to the required depth gradually. The method of setting ridges depends on the custom of the locality and on whether the field is lea or stubble.

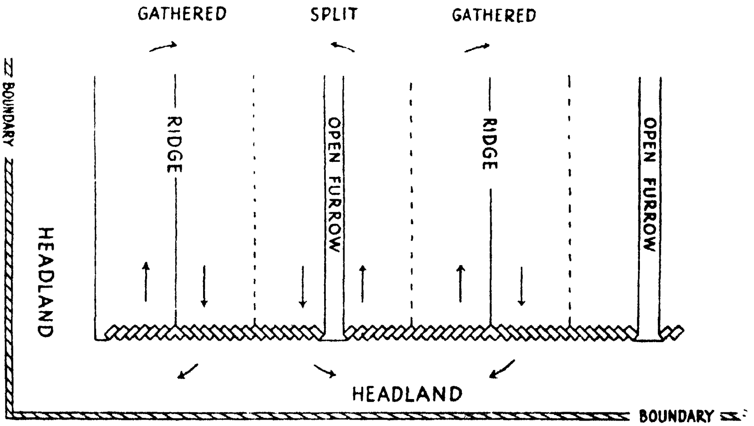


FIG. 4.—Diagram showing Method of Ploughing. The arrows indicate the travel of the plough in first gathering round the ridges and then splitting from the dotted lines to the finish at the open furrows

When marking out a field for horse work it is usual to put the first ridge a quarter-land width from the sideland mark. Where the ridges have been set out 22 yds. apart, the method of working is to plough round and round the first ridge in a clockwise direction until a strip 11 yds. wide has been turned over: this process is called "gathering." The ploughman then proceeds to the second ridge and again gathers 5½ yds. of land on each side. Henceforth it saves time to return to the unturned land between the two gatherings and plough it outwards in the direction of the two ridges by moving in an anti-clockwise direction until the whole of the soil is turned over. This part of the work is called "splitting" or "casting" (see Fig. 4). This method of working entails very sharp headland turns and is not to be recommended for tractor work, particularly with large trailed ploughs. For tractor ploughing the first ridge is set at a distance three-quarters

of a " land " width from the sideland mark. The driver splits this three-quarter " land " between the ridge and the sideland until he is left with an unploughed strip a quarter " land " wide. He now gathers round the ploughed land on the first ridge until this quarter "land" together with a quarter of the first full " land " is ploughed. The second ridge is treated in exactly the same manner as the first. As the unploughed land narrows, the hitch is adjusted as required to correct inaccuracies so that there will be a straight and uniform strip to turn into a neat finish. The ploughing depth may be reduced slightly just prior to the finish to avoid very deep open furrows.

When the last slice is turned over an open furrow two widths wide is left between the ridges. It is usual to leave the land in this condition, but where greater drainage is required a " mould-furrow " finish may be given, which consists in turning one more furrow out of the subsoil. Except where the open furrows are required as surface drains, the last furrows must be ploughed back so as to level the ground before the commencement of the working of the land as a seed-bed.

When the land is ploughed again, the furrow-slices are turned in the opposite direction so that the open furrows are converted into ridges, and the ridges into open furrows; thus the surface of the field is kept practically level. On certain heavy, wet soils, where narrow, high lands are desirable, it is customary to ridge up five times and plough back four times in every nine ploughings; this practically balances the washing action of rain, which in time tends to level down the crests and fill the depressions.

In horse ploughing the headland may be gathered at one ploughing and split at the following, or where it runs right round the field, as is usual in tractor ploughing, it may be ploughed round and round, turning it inwards one season and outwards the next.

An alternative method of tractor ploughing which avoids waste of time in turning is to go round and round the field. This may be done by turning the furrows towards the boundary and continuing until the remaining small patch in the middle of the field can be ploughed as a " land " by turning on the ploughed land at its ends. As this method leaves very rough diagonals (where the plough changes direction), these may be marked off as headlands beforehand and ploughed afterwards. If the ploughing is started in the middle there is no need for diagonal headlands,

but, at any rate on the first occasion, it is a more complicated business to fix on the right place to start.

A plough hitch has horizontal and vertical adjustments. If the horizontal adjustment is incorrect the plough may " crab," and the furrow width of a single-furrow plough and the front furrow width of a multi-furrow plough may be smaller or greater than required. " Crabbing " increases the draught, throws unnecessary pressure on side caps or wheels, and may make the outfit unmanageable. Ideally all side-drag should be eliminated, but where this is impossible, as is often the case with track-laying tractors, the hitch should be arranged to distribute the side-drag equally between the tractor and the plough. On mounted ploughs the front-furrow width is controlled by turning the cranked cross-shaft by means of which the plough is attached to the lower links of the tractor. Correct vertical adjustment allows the plough to run smoothly without any tendency for it to be lifted out of the ground or for excessive pressure to be exerted on the land wheels. With a trailed tractor plough the hitch should be parallel with the ground surface, and under no circumstances should it slope downwards from the plough to the tractor. Excessive pitch on the shares is made evident by uneven furrow bottoms. Failure of a plough to penetrate the ground and maintain ploughing depth may be due to inadequate pitch, but before any pitch adjustments are made the shares should be examined, and if there are signs of excessive wear new shares should be fitted. If, after this has been done, the plough still fails to pull into the ground, the pitch should be increased. On some multi-furrow ploughs the bodies can be adjusted individually for pitch, but on ploughs mounted on a tractor's three-point implement-suspension pitch of all the bodies is controlled by shortening or lengthening the top suspension link. The pitch should be as little as possible, while remaining consistent with satisfactory working. As well as pointing slightly downwards, the share should also point slightly towards the furrow wall. The setting of coulters has been discussed on pages 123-124. On horse and tractor trailer ploughs the land and furrow wheels regulate ploughing depth and keep the plough level. Most mounted ploughs have depth-regulating wheels, but on the Ferguson tractor depth is controlled indirectly by the power lift (see p. 127). Mounted ploughs are kept level by varying the relative lengths of the lift arms attached to the lower links.

No plough will produce satisfactory results unless its rubbing surfaces are scouring properly; that is, the metal must take on such a high polish that the adherence of soil is absolutely prevented. Ploughs that are in good condition should have their shares and mould-boards coated with an efficient rust preventive before they are set aside, so that good work is possible immediately the implement is returned to use. When a plough fails to scour and soil collects in the concavity of its mould-board, it is evident either that the metal is unsuitable or that the breast is of the wrong shape.

When the object of ploughing is to bury herbage, a skim coulter should be fitted if conditions are suitable. The skimmer pares off that portion of the vegetation which grows on the shoulder of the furrow, where, because of exposure to air and light, the vegetation is liable to continue its growth if an ordinary coulter is used. Where crops are being ploughed in, or long manure is being buried, a drag chain and weight should be employed to pull the material beneath the furrow.

Different styles of ploughing are illustrated in Plate IV. No. 1 is a style adopted for lea work, and in the preparation of land for the broadcasting of seed: the furrows are well set up and a large surface is exposed to the weather. No. 2 is the ordinary style: the breadth of the furrow is greater than its depth, and the furrow is inverted without being broken. No. 3 is the work of a plough with a digging breast which pulverizes the furrow as it turns it over: it is the common style of spring cross-ploughing for the production of tilth. In No. 4 the relatively broad and shallow furrow-slices are completely inverted to permit of subsequent thorough consolidation, as for the direct re-seeding of grassland.

The following are the requirements in good ploughing: each furrow must be straight from end to end; the top lines of the furrow-slices should be absolutely uniform without breaks and depressions, and the furrow-slices should be of uniform thickness; all vegetation, manure, etc., should be properly buried; there should be no unturned ground. Where the land is ploughed to receive broadcast seed the furrows should be trapezoidal and well set up, there should be no gaps through which seed might fall too deep, and the land should be left as firm as possible. Where digging ploughs are used the soil should be completely broken up, not only on the surface but to the full plough depth, and there should be no large air spaces.

CULTIVATORS

Cultivators are used to break up land that has lain in the furrow throughout the winter, to level land that has been tracked by the carting off of roots, for summer fallowing, stubble breaking, and the inter-row cultivation of various crops such as potatoes, vegetable crops, and fruit trees and bushes. Much of their work is heavy and they have therefore to be stoutly built. Cultivators vary considerably in detailed design but all are built on the same general principles—a two-wheeled steel frame to which are attached a number, usually nine or eleven, or more rarely thirteen, straight or curved, rigid or spring-mounted tines. The tines are arranged in rows, *i.e.* they are staggered, to obtain the maximum clearance between adjacent tines and thereby allow rubbish to pass between them without causing blockages. The lower ends of the tines carry detachable steel points. Various types of point are provided for different classes of work. The type most frequently used for general cultivating is the double-ended narrow reversible point, but broader points are available for shallower work.

The Horse Cultivator.—The horse cultivator has a single castor wheel to carry the weight of the front of the implement. Depth is controlled by two levers operating on the cranked axles of the main land wheels and a third lever adjusts the angle of the points to the soil, thus giving the desired amount of penetration. Martin's Springtine Cultivator is illustrated in Fig. 5. In this implement the tines are not rigidly attached to the framework but are connected by flat steel springs which, by yielding a little when the tines hit a large stone or other obstruction, allow the shares to override it; moreover, the spring gives the tine a slight vibrating motion which is said to produce a finer mould. This implement may be modified for the cleaning of root crops and for the drawing and splitting of ridges. This is possible because of its adjustable track, its removable and adjustable tines, and the special ridging bodies provided for fitment to the frame.

The Tractor Cultivator (Plate V, *A*).—Tractor cultivators are heavier and more stoutly constructed than horse cultivators because they have to withstand much greater strains and stresses. Depth control is usually by a screw adjustment operating through the cranked axles of the land wheels, although on a few makes it is by levers and quadrants. A self-lift of the rack and pinion type, brought into action through a trip cord pulled by the tractor

driver, raises the tines out of work. The Ransomes' Equitine cultivator is an interesting type because the tines can swing in their mountings and are joined together by flexible chains and levers. When a tine hits an obstruction it swings backwards, passes over the obstruction, and is then pulled back into work by the forces acting on the other tines and transmitted to it through

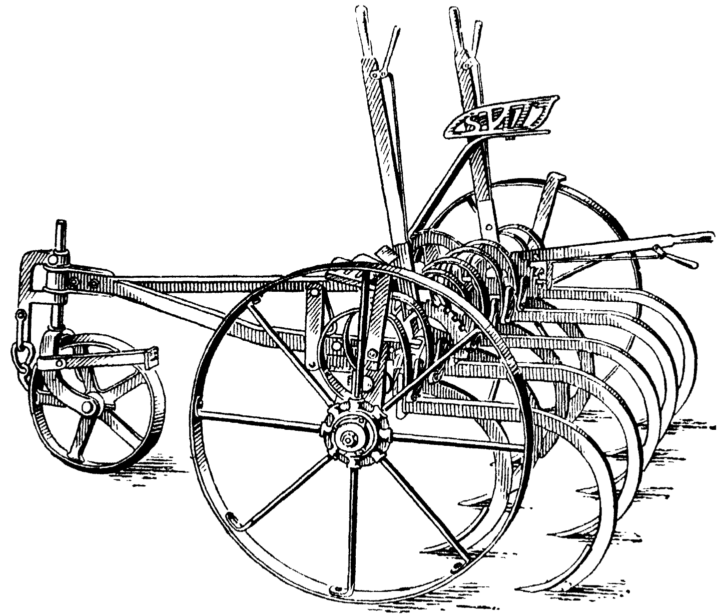


FIG. 5.—Martin's General Horse Cultivator

the connecting chains. On another type of general-purpose cultivator (the Ferguson) coiled tension springs hold the tines in work but allow them to rise if they hit an obstruction. Cultivating tines are also mounted on tractor tool-bars, but, with a few exceptions, these outfits are only suitable for the inter-row cultivation of root crops and not for general cultivating.

Rotary Cultivators.—These are machines provided with power-driven hooks or tines that tear the soil into more or less fine, loose fragments, thus producing in one operation a tilth suitable for a seed-bed. The tines are mounted on horizontal or vertical axes that fit behind a tractor, the whole forming a self-contained, self-propelled unit; but in some makes the cultivator is a separate attachment that is pulled by an ordinary agricultural tractor and

actuated from the power-take-off (see Plate V, *B*). The size of rotary cultivators varies from a small "walking" machine designed for garden and orchard work, through a range requiring medium tractor power, to the very powerful "Gyrotiller" which can cultivate to a depth of 18 in. and even clear land of scrub.

As compared with ploughs and ordinary cultivators, rotary cultivators have the disadvantages of being unable to bury turf, trash, or manure, and of producing in some soils a tilth that is too "fluffy" for good planting and one that is liable to cap after rain. Rotary machines are, of course, quite unsuitable for use in winter when land is wet and easily puddled. On the other hand they are excellent for forming a surface mulch and for destroying small weeds as required in the cultivation of an orchard.

The Steerage Horse-hoe.—The steerage horse-hoe is used for hoeing crops, particularly root crops, grown in rows on the flat or on ridges. The commonest type (Fig. 6) has a tool frame to which the hoe blades, cultivating tines, handles, and sometimes depth regulating wheels are attached, loosely connected to a two-wheeled fore-carriage. The wheels on the fore-carriage can be moved to any position on the axle to fit between the rows. As the hoe travels through a crop a man walking behind steers the tool frame independently of the fore-carriage and prevents the tools from damaging the crop. In the "sliding-axle" type of steerage hoe the tool frame is attached to the axle carrying the two land wheels and is steered by sliding the axle from side to side through the wheels. In another type steering is effected by changing the direction of the land wheels in the same way as a motor car is steered.

The number of rows hoed at once is either equal to or is an exact sub-multiple of the number of coulters in the drill. This is necessary if accurate close hoeing is required, because, in drilling the seed, the outer coulter of the drill cannot in practice be run exactly parallel to the previous row. The hoe blades are staggered on the frame so that cut weeds and stones do not jam between adjacent hoes. The hoe blades are sometimes mounted in such a way that they rise and fall with irregularities in the surface of the ground. Individual hoes or groups of hoes may be so mounted, with a spring in each mounting to keep the hoes in work. Spring-loaded hoes work well under most conditions, but when the ground is hard they may not be so efficient as hoes mounted on rigid stalks

because the man steering is unable to force them into the ground by exerting pressure on the handles attached to the tool frame.

A steerage hoe hauled by a tractor requires an operator in addition to the driver. Tractor steerage hoes may be special implements or they may be converted general-purpose tool-bars.

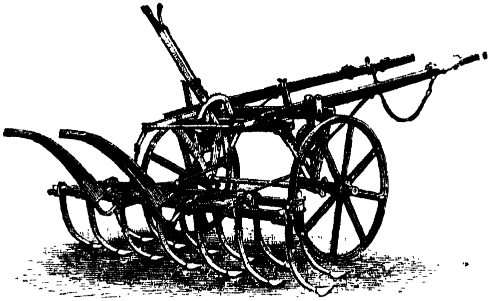


FIG. 6.—Steerage Horse-hoe (Cooke)

The Drill Horse-hoe.—Drill horse-hoes, harrows, cultivators, scufflers and grubbers are implements designed for cultivating crops grown on ridges, usually one row at a time. The simplest hoe has a narrow frame with handles at the rear, and in front a small wheel, adjustable for height, for controlling the depth of working. The cultivating tools are attached to the frame. The expanding type of horse-hoe shown in Fig. 7 consists of a frame,

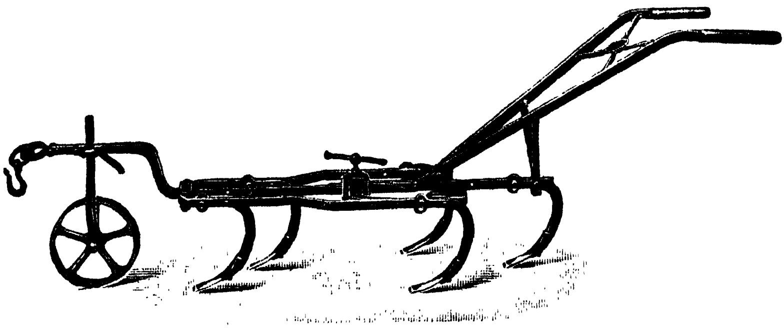


FIG. 7.—Expanding Horse-hoe

the side members of which are hinged in front and can be fixed to give any desired width of cut by means of a set screw; it is kept in balance by means of its handles, and its depth of working is controlled by moving the wheel up or down in its socket. Horse-hoes vary in size and weight; heavy two-horse implements are

made which allow of deep work, and, on the other hand, light five-tine hoes can be obtained suitable for market gardens.

The wide range of hoe blades manufactured to suit all purposes fall into two well-defined groups: A-hoes and L- or side-hoes. A-hoes are used for cultivating the centres of the rows, whilst L-hoes are run close to the plants. If the row width is so wide that a pair of L-hoes do not completely cover the row, A- and L-hoes are used together; but on narrower row widths A-hoes are used when the plants are either so small that close hoeing is impossible, or so large that only the centre of the row need be cultivated. On the other hand L-hoes are essential for close-hoeing. A pair of dished discs set at an angle to each other and straddling the plants is frequently used for the cultivation of roots grown on the flat and on the ridge. They pull soil away from the plants and thereby facilitate singling. On ridge root crops in wet districts, cutting the weeds with hoe blades does not always kill them, and the only effective control is to use discs to smother them.

Row-crop tractors, with rear and underslung tool-bars, are being used on an increasing scale for grubbing potatoes and hoeing root crops grown on the ridge. (See Plate VI, *B*.)

Gapping Machines.—The ordinary horse-hoe is used for gapping root crops grown on the flat by driving it across the rows. The Kent and Dixie gappers (Plate VII, *A*) are examples of special along-the-row gapping machines; models are available for both flat and ridge work. Gapping is successful only if the stand is uniform. The width of land left uncut (*i.e.* the size of the bunch) is adjusted to suit the stand, and the distance apart of the bunches is varied on the Kent and Dixie machines by altering the speed of rotation of the gapping knives relative to the forward speed. Two or more of the Dixie units may be mounted on a tractor tool-bar.

HARROWS

The Zigzag Harrow.—Zigzag harrows (Fig. 8 and Plate VIII, *A*) of the ordinary type have fixed vertical tines, and are constructed in many different sizes and weights. The lightest type, which, however, may have a track as wide as 18 ft., is used for covering grass seeds, and consists of a light framework with very short iron teeth; it takes the place of the old-fashioned brush harrow for the lightest class of work. The heavier makes have

iron frames and longer tines, so that they have a greater penetration in hard land; their track is 7 ft. 6 in. to 9 ft., and all but the heaviest models can be drawn by two horses. For tractor work the same types of harrow are employed, but the sets may be 20 to 30 ft. wide, and may be equipped with a lift which, on engaging a trip clutch, raises and lowers the harrows during forward travel, thus allowing any accumulation of rubbish to drop from the tines. Alternatively three harrow leaves are mounted on the back of

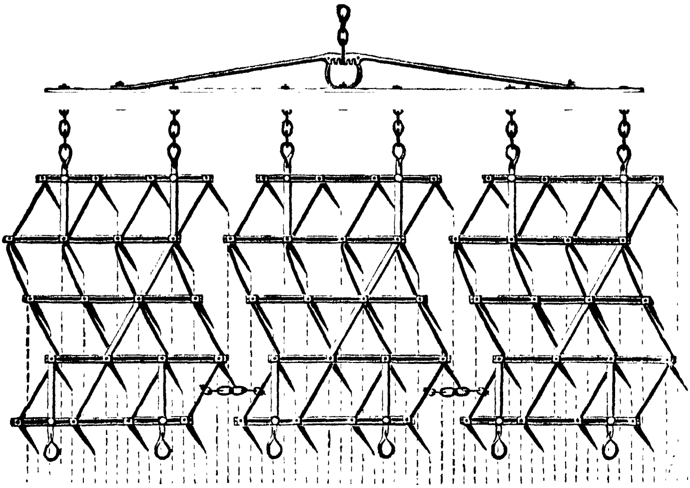


FIG. 8.—Zigzag Harrow (Sellar)

the tractor and are raised and lowered on the power lift. The side leaves are raised into the vertical position to reduce the overall width for transport.

An improvement on the ordinary harrow is an implement fitted with hinged teeth, the angle of which is controllable by means of a tilting lever. Such an arrangement allows of a forward setting of the tines, which enables the implement to work to a greater depth if the land is hard, and of a backward setting, to avoid clogging of the teeth when the surface is strewn with weeds.

The Drag Harrow.—Fig. 9 illustrates an ordinary type of drag harrow. An implement of this kind has usually a 6 ft. track, and is intermediate in its action between a harrow and a cultivator. The long tines with their forward curve penetrate a considerable way into the soil and create a fairly deep tilth. This harrow is very largely used for dragging out creeping weeds like couch-grass,

and it is fitted with handles so that it may be raised and freed from rubbish from time to time.

The Saddle-back Harrow.—Saddle-back harrows are used

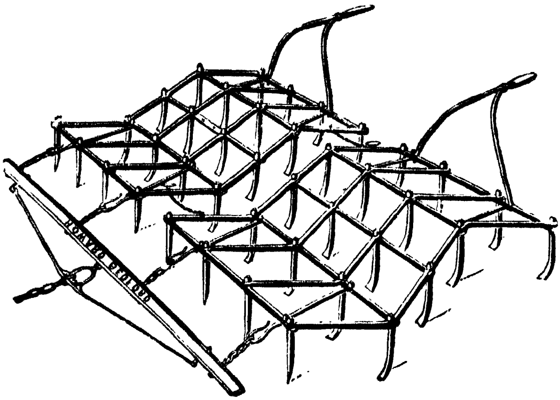


FIG. 9.—Drag Harrow (Howard)

for pulling down potato ridges. As the name implies, each harrow leaf is shaped to fit the ridge so that the straight tines disturb the weeds at the base as well as on the top of the ridge. Each harrow

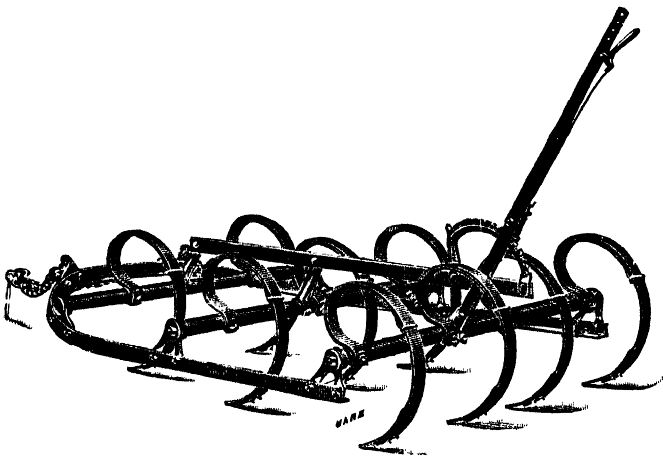


FIG. 10.—Spring-toothed Harrow (Sellar)

section is divided longitudinally into two, and the halves are hinged together, thus enabling the shape to be adjusted for high sharp-pointed and low flat ridges. Saddle-back harrows consisting

of only two sections are normally horse-drawn. Plate VII, *B*, shows four sections attached to a direct-mounted rear tool-bar.

Spring-toothed Harrows (Fig. 10) have an action somewhat similar to that of drags, but the angle of the spring tines can be instantly altered to suit the condition of the land or, when used for weed dragging, to free the implement from trash. They are sometimes mounted on the back of a tractor.

The Chain Harrow.—Chain harrows, constructed of link pieces which may or may not carry small tines, are completely

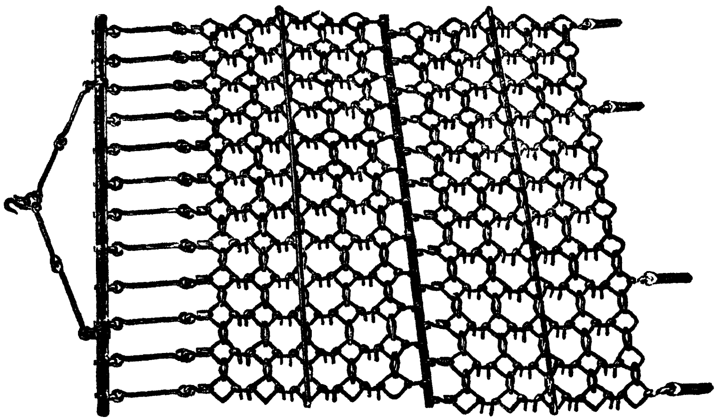
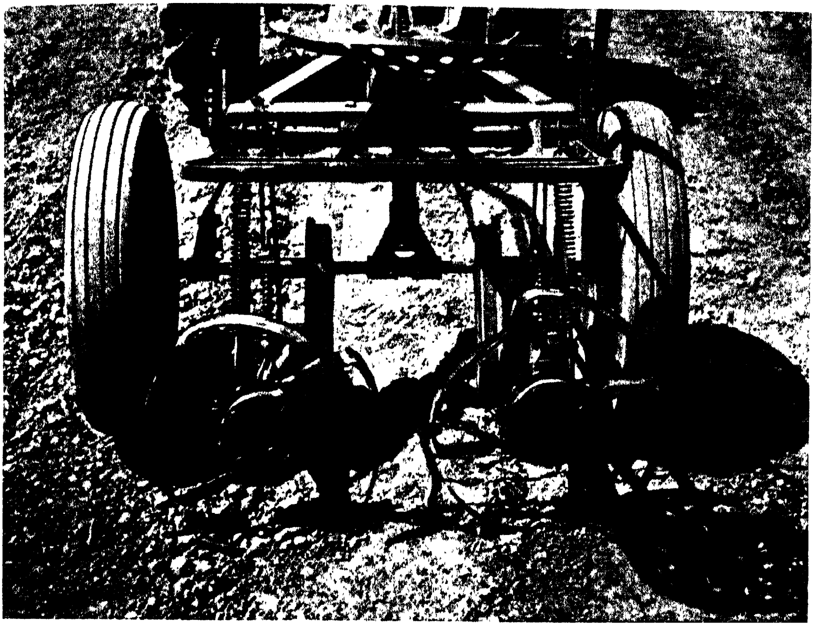


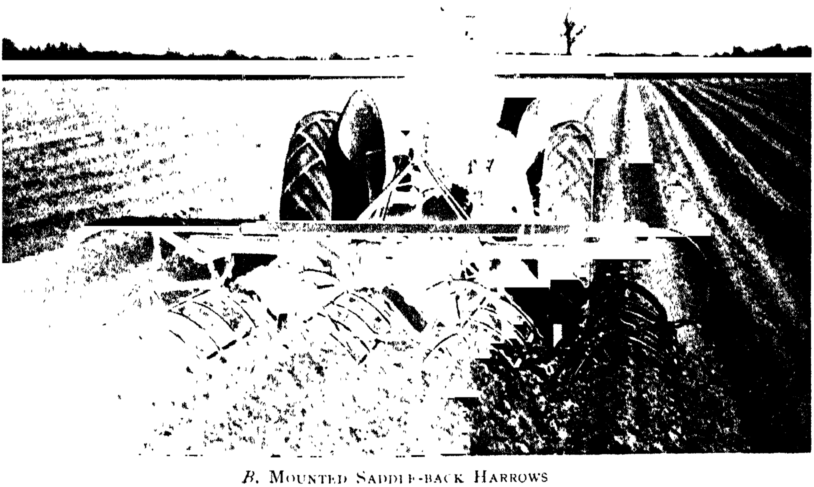
FIG. 11.—Chain Harrow (Homer)

flexible. They are most largely used for spreading droppings, mole-hills, etc., on grassland, but they may be employed for harrowing down potato drills and rolling together the weeds that have been dragged out of fallows. Some models have knife tines on one side and ordinary straight tines on the other, or tines may be present on one side only. A flexible harrow has a better rubbing effect than an ordinary harrow and under some conditions may be superior for producing a surface tilth.

The Disc Harrow.—This implement, which is illustrated in Plate III, *B*, is probably the most efficient type of harrow for pulverizing and loosening the surface soil. Not only is it used for the creation of a tilth on ordinary arable land, but it may be worked on grassland to cut up the surface and promote aeration, or in preparation for manuring and renovation. No other harrow can work so well on soddy land, since the rolling action of the discs precludes all possibility of clogging or of pulling up turf or

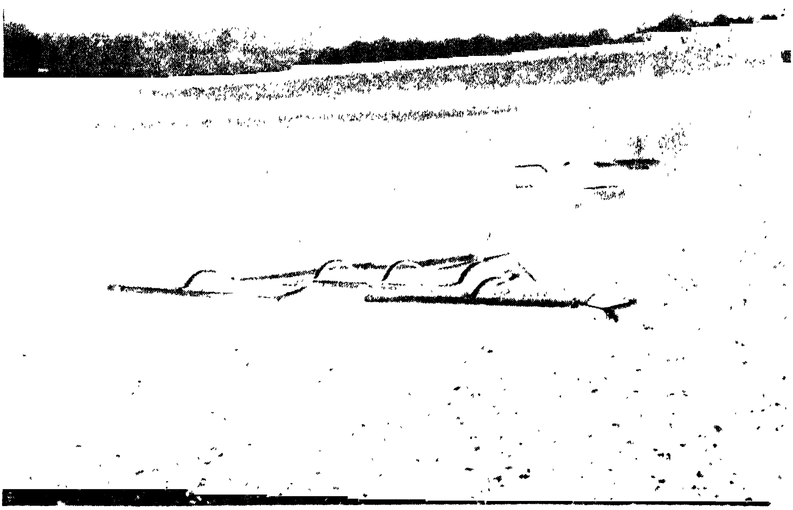


A. Gapping Machine (Dixie)



B. Mounted Saddle-back Harrows

A. Multiple Harrow and Hitch



B. Cambridge Rollers and Hitch

buried rubbish. Moreover, the implement exerts more compression than a tined harrow on the lower horizon of the soil. It is therefore very valuable for obliterating the air spaces that tend to cause trouble when tough old swards are ploughed, and for producing a firm seed-bed on any land that tends to " lie hollow." Finally, the discs have a slight digging and soil-turning action, and may be used for the destruction of weeds that have got beyond the control of ordinary harrows; but discs should not be used on couch-infested land.

The modern disc harrow is designed for tractor work and consists of two double gangs of dished discs. The discs of the first two gangs move the soil away from the centre of the implement and the rear discs move the soil in the opposite direction. The angle that the discs make with the line of draught is easily adjustable. This adjustment is sometimes made through the lift mechanism on the tractor. The depth of working is determined by the angle of the gangs to the line of draught, the curvature of the discs, and the weight of the harrow. Weight pans are usually provided to take added weights when it is necessary to get extra penetration. Small wheels, with a simple jacking arrangement attached, are used for transporting disc harrows on hard roads. One wheel is put on each gang. Small sets of discs may be tractor-mounted, in which case they are raised clear of the ground on the lift for turning on the headlands and for transport. Smaller two-gang disc harrows are sometimes used with horses.

The Pitch-pole Harrow is a dual-purpose implement which takes the place of a drag harrow for arable land and also acts as a grassland renovator. It possesses double-ended tines, and a knife-edged pattern is employed when the harrow is used for tearing old turf and aerating pasture. If the knives gather trash they can be cleared by allowing them to revolve or "pitch-pole." Three wheels are provided for transport; the depth is set by hand levers and the pitching action is controlled by means of a cord to the trip lever. Tractor-mounted models are now available.

The Cultarrow is a tractor-mounted tool in which the two transverse members carrying the tines have a reciprocating motion across the direction of forward travel. Power for the motion is obtained from the tractor power-take-off. The Cultarrow has a greater effect on tilth than ordinary tined harrows and has been found very useful for harrowing out potatoes behind the pickers.

ROLLERS

Rollers vary in diameter, width, weight, shape, and the materials of which they are constructed; they are manufactured to suit all ordinary and special purposes. Probably the heaviest and most effective that are in use are the old solid stone rollers still seen in many quarrying districts. As the material is so exceptionally heavy these rollers have to be made small in diameter,

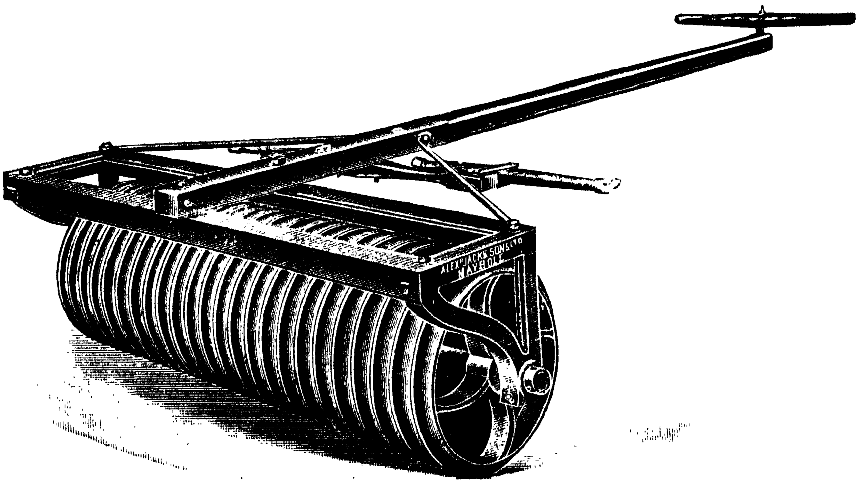


FIG. 12.—Cambridge Roller (Jack)

and consequently they exert an enormous crushing effect; as, however, their draught is particularly heavy, their use is generally confined to bad years, when a tilth is difficult to prepare. The most common rollers are constructed of iron, in the form of cylinders mounted on a long axle, the division into sections allowing of more easy turning at the headlands. Sometimes a single-cylinder water-tight barrel is used, which can have its weight increased by the addition of water, the quantity being determined according to the nature of the work to be done. The heaviest iron clod-crushers are Cambridge (Fig. 12 and Plate VIII, *B*) and Crosskill rollers, the former being built up of heavy ribbed and the latter of heavy toothed sections. This construction reduces the bearing surface on the ground and so increases the pressure on clods. Small rollers for a single horse are fitted with shafts, but large two- and three-horse sizes have a framework

and one or two wheels to support the hitching gear. When rollers of the latter type are used on hilly farms they must be fitted with brakes in order to avoid serious accidents. Light one-horse rollers are frequently made of wood, either in the form of a turned log or built up from staves; they are useful for light work but have little value for clod-crushing. When it is desired to increase the weight of a light roller, iron cart axles and heavy stones may be securely fastened to the framework. Special diabolo-shaped rollers are made for rolling turnip drills. These are particularly useful in producing the consolidation necessary to bring about the germination of the seed in a dry spring. Tractor rollers are often made up in sets of three sections, each set covering a width of 20 ft. or more. For transport along roads and through gateways the three sections are pulled in tandem. It is worthy of note that the effectiveness of rolling is decreased if the implements are driven fast.

A furrow-press is a special type of roller used immediately after ploughing in order to secure a firm bottom for the seed-bed. Furrow-presses are popular in certain areas, especially where wheat normally follows clover or other leas. The essentials are a frame, with shafts or hitch-bar, mounted on an axle which is supported on the near or land side by an ordinary wheel but on the off side carries a number of heavy press wheels with wedge-shaped rims which bear into the furrow grooves. The presses are adjustable for width of furrow. A horse implement has two presses, but in the case of a tractor, which pulls the press immediately behind its plough, the presses correspond in number to the plough bodies.

SPRAYERS AND DUSTERS (See Plate IX)

Many and various substances are employed for the control of insect and fungoid pests and for the destruction of weeds. Only small quantities of the chemicals are required, and to obtain uniform distribution they are usually applied either as dilute solutions or as finely divided dusts. Many of the chemicals are corrosive and those parts of the machines which come into contact with them are made of special alloys. In most machines the liquid is converted into spray by forcing it through specially designed nozzles; on others the process is effected by feeding a thin stream of the liquid into a strong air blast. Many types of spraying machines are in use, varying from small hand-operated

knapsack appliances to large horse- or tractor-drawn or tractor-mounted units with mechanical pumps. In some the liquid container is air-tight and a pump is employed to force out the spray by means of air pressure; in others the liquid itself is pumped, but an air cylinder and a pressure release valve are interposed to equalize the pressure before it reaches the nozzles. Agricultural spraying machines generally work at low pressures—about 30 to 40 lb. per sq. in.—but in horticulture much higher pressures—as high as 400 to 500 lb. per sq. in. or more—are employed.

When the area to be sprayed is not large, a barrel to hold the liquid may be placed in a farm cart or tractor trailer while the spraybar, carrying the nozzles and hand pump, is clamped on to the back of the vehicle; a man in the cart works the pump. It is more usual, however, to employ a sprayer with a tank capacity of 50 to 150 gals., and provided with a pump which may be driven from the axle, by a small petrol engine or from the tractor power-take-off. The power-operated pump may also be used for filling the machine, thus saving a great deal of time on the headland. Such machines have an effective spraying width of about 5 yds. and, allowing time for filling, spray about 2½ acres an hour. Different types of spraybar can be attached to the machines. For spraying weeds in corn all the nozzles are at the same level and face downwards, whereas for spraying potatoes against blight some of the nozzles are on pendants and direct the spray upwards on to the under surface of the foliage. The use of dilute solutions demands an adequate supply of water and means that a great deal of time is spent in preparing the solution and filling the sprayer. These difficulties have been overcome by the introduction of "low-volume" sprayers, which are machines capable of applying small quantities per acre of concentrated liquid.

Dusting is not always so reliable as spraying, but it can be done much more quickly and with less labour. The most commonly used duster is a very simple machine. The powder is fed into a fan and is blown on to the crop. Quantities as low as 10 lb. per acre can be applied with a satisfactory degree of uniformity. Small hand-operated dusters are available, but for field work, especially on potatoes, large eleven- and thirteen-row machines, capable of dusting 7 acres an hour, are used. The fan may be driven from the axle of the machine or it may be power-operated from a small auxiliary engine or from the tractor power-take-off.

Tractor-mounted dusters include the recently introduced machine on which the exhaust gases of the tractor distribute the dust.

Fumigation is employed for the control of certain pests. The chemical is vaporized by mixing it with hot gases and is then released under a very large sheet trailed over the growing crop. These specialized machines are in the hands of contractors.

Aircraft are being increasingly employed in the new countries for spraying and dusting. The small size of the fields in many parts of Britain presents a difficulty which may probably, however, be overcome by the use of the helicopter.

CHAPTER VI

TILLAGE—WEED CONTROL

THE final objectives of tillage operations are, on the one hand, to produce in the soil a physical state favourable to the establishment and growth of crop plants, and, on the other, to control weeds so far as to prevent them from competing seriously with the cultivated plants for light, soil moisture, and plant nutrients.

Some particular tillage operations aim directly at one or other of these objects. For instance, the spring cultivation of autumn-ploughed ley for a crop of oats may have as its one aim to produce a suitable seed-bed—a zone of fine, crumbly soil in which to place the seed and, below this, a well compacted layer in which the plants will obtain a firm roothold and a supply of moisture. Again the inter-row cultivation of a root crop aims at destroying the weeds which would otherwise smother the slower-growing crop plants.

In other cases the objective is a long-term one. For instance, when we plough in autumn in preparation for a root crop we hope that we are creating a condition in which the soil will benefit from winter weathering—*i.e.* will remain sufficiently open to allow rain to penetrate easily into the subsoil and will be fully exposed to the action of frost. In autumn ploughing we shall also, however, be burying the stubble of the preceding corn crop and we may take the opportunity of incorporating with the soil a dressing of dung.

As regards weed control, there are certain indirect measures, such as the proper design of rotations and the use of "smother crops," which are discussed in Part IV, as aspects of farm organization. Weeds of grassland are dealt with later (pp. 486-489). Here we are concerned with direct measures of controlling weeds in arable land.

Two of the methods that are still employed to-day are of great antiquity. The one is *fallowing*—*i.e.* the devotion of a growing season, in whole or in part, to the destruction of weeds, the land carrying no crop while the process is being carried out. In this country to-day fallowing consists simply of a series of tillage operations, but in many primitive systems of farming the burning

of the weed vegetation is part of the process. The operation of paring and burning—" Devonshiring "—survived in parts of this country until after the middle of last century. The other old method is the hand pulling, or hoeing up, or chopping, or spudding of weeds in the growing crop.

The first important innovation was the introduction of drill or horse-hoeing husbandry, made possible by the invention of the drill about 1730, but becoming widespread only from about 1800. Much later still (in 1896) came the discovery that a solution of copper sulphate, of suitable strength, would kill certain broad-leaved weeds (notably yellow charlock) while causing relatively little damage to cereal plants in the early stages of growth. To-day there is a considerable choice of chemical weed killers, including some that are highly selective in their action as between one species and another. Thus to-day, in dealing with weeds, we can combine measures such as rotational cropping with tillage operations and the use of chemical herbicides.

COMMON WEEDS [1]

Almost any native or introduced plant may be found as a weed—*i.e.* growing where it is not wanted and competing with the cultivated crop for light, water, and plant food. Crop plants themselves must be regarded as weeds if they grow where not intended. Thus " ground-keeper " potatoes can be quite troublesome in fields of roots, and brown mustard, formerly cultivated in East Anglia, could become about as noxious as its relative charlock. Again, plants of one variety of potato, growing in a seed-crop of another variety, must be treated as weeds. Such are commonly called " rogues." A complete list of British weeds would include some hundreds of species, but the number that cause really serious trouble in any given area and under any particular system of cropping is usually small. Some few, like the couch-grasses, docks, and the field or creeping thistle, are very widely distributed, but otherwise the weed flora is closely related to the soil and climatic conditions and the cropping system. For instance, in the heavy land arable districts of the midland and eastern counties, where winter wheat is the predominant

[1] Students who do not know the common weeds mentioned in this text should consult an illustrated British Flora such as that of Bentham and Hooker, or of Clapham, Tutin, and Warburg.

cereal, the characteristically abundant species are wild oats (the native *Avena fatua* and the introduced *A. ludoviciana*), slender foxtail or black-grass (*Alopecurus mysuroides*), corn buttercup (*Ranunculus arvensis*), shepherd's needle (*Scandix pecten-veneris*), *Agrostis* couch or water-grass and, less generally, the wild onion or crow garlic (*Allium vineale*). By contrast, on fertile loam soils in eastern Scotland, where spring-sown oats and barley predominate, the major problems are presented by yellow charlock or wild mustard (*Sinapis arvensis*) and couch (*Agropyrum repens*), while on light and lime-deficient land in the same area spurrey (*Spergula arvensis*) is the most aggressive species. Again, in the intensively manured market-garden area of Bedfordshire, on the Greensand formation, the chief trouble is caused by quick-growing annuals such as chickweed (*Stellaria media*), the mayweeds and chamomiles (*Anthemis* and *Matricaria*), fat hen or goosefoot (*Chenopodium album*), and the annual or small nettle (*Urtica urens*).

From the farmer's point of view the most useful classification of weeds is according to habit of growth and method of reproduction.

The *Ephemerals*, so called because they grow from seed, flower and shed their seed all in a matter of weeks, form a fairly distinct group. Most are of low growth or of sprawling habit so that they cannot compete seriously with a quick-growing and tall crop like spring oats. On the other hand, they compete strongly with, and may smother, crops like carrots and onions which are slow to become established. The ephemerals are therefore the most important group in market gardening. One or two, notably ivy-leafed speedwell (*Veronica hederaefolia*), which are frost-hardy as seedlings, can be troublesome in winter corn during the early spring. Otherwise in farming they cause most concern in sugar-beet and roots. Examples are the chickweeds (*Stellaria* and *Cerastium*), shepherd's purse (*Capsella bursa-pastoris*), the speedwells (*Veronica sp.*), groundsel (*Senecio vulgaris*), and annual meadow-grass (*Poa annua*).

The *Annuals*, which produce only one generation a year, may usefully be divided into those whose seedlings are frost-hardy and those others whose seedlings are killed in the average British winter. The first find a favourable environment in winter cereals, shedding their seed before the grain is ripe. These include, besides the wild oat, slender foxtail and corn buttercup already

mentioned, poppies (*Papaver sp.*), and cornflower (*Centaurea cyanus*).

Annuals whose seedlings are not frost-hardy, and which therefore are rarely troublesome in winter grain, include yellow charlock, and its less widespread but less easily controlled relative white charlock or runch or wild radish (*Raphanus raphanistrum*); mayweeds and chamomiles, goosefoot or fat hen (*Chenopodium album*), and the related oraches (*Atriplex*), fumitory (*Fumaria officinalis*), redshank or willow weed (*Polygonum persicaria*); knot-grass (*P. aviculare*) and bearbine, climbing buckwheat, or black bindweed (*P. convolvulus*); cleavers (*Galium aparine*); annual sow thistle (*Sonchus*); spurrey; corn marigold (*Chrysanthemum segetum*); annual nettle; hemp nettle (*Galeopsis tetrahit*), and others of less widespread distribution.

A further useful distinction may be made, as among the annuals, according to the length of the period of dormancy of the seeds. Given suitable conditions, the seeds of chickweed, for example, will germinate as soon as they are shed, whereas those of charlock, wild oat, black-grass, and poppy have to undergo a process of "after ripening," which may last for several months, before they can be induced to germinate. Still others, shed in summer, refuse to germinate until the following spring; these include fat hen, knot-grass (*P. aviculare*), mayweed, and corn marigold. Sometimes even a minor difference may be important. Thus in the south midlands the seeds of black-grass can often be induced to germinate by October, so that the seedlings can be destroyed in the process of sowing wheat; whereas wild oats, even of the winter species, will rarely do so, more usually springing up some time after the wheat is sown.

Biennial Weeds such as spear thistle (*Carduus lanceolatus*), wild carrot (*Daucus carota*), and ragwort[1] (*Senecio jacobaea*), are unimportant in arable crops since any plants that gain a footing will ordinarily be destroyed by ordinary tillage operations in their first year, *i.e.* before they have reached the flowering stage.

The *Perennials* that infest arable land are almost exclusively those with underground stems. The only important exception is the dock (*Rumex sp.*), which, although a tap-rooted plant, has the rather uncommon capacity (shared with the dandelion) of producing adventitious buds from portions of root. Plants with

[1] Ragwort sometimes behaves as a perennial, and does so normally if the flowering stems, which appear in the second year, are cut down.

surface runners, such as silverweed (*Potentilla anserina*) and creeping buttercup (*Ranunculus repens*), are generally destroyed by good ploughing at a reasonable depth, especially if drainage is good.

The feasibility of destroying underground stolons depends largely upon the depth at which these are found. Thus watergrass usually runs at a depth of about 2 or 3 in. and couch-grass at 3 to 4 in., *i.e.* well within the normal plough depth even on thin soils. Those of the creeping or field thistle occupy an intermediate position, and it is often necessary to plough at more than the normal depth, or to subsoil, in order to reach them. Those of the bindweeds (*Convolvulus sp.*) and coltsfoot (*Tussilago farfara*) are quite beyond the reach of ordinary implements.

Two noxious species have bulbous underground stems. The one, bulbous tall oat grass, known also as onion couch or knot-grass (*Arrhenatherum avenaceum*), has storage organs like strings of miniature onions which can be dragged out of the ground without much breakage if the soil be first very thoroughly loosened. The other, wild onion (*Allium vineale*), which has a bulb like a small tulip with attached bulbils, cannot be dragged out by any implement.

WEED CONTROL WITH CHEMICALS

While it remains as true as ever that the basis of clean farming should be a sound rotation and good cultivations, the development since 1940 of a range of selective weed-killing chemicals has put into the farmer's hands a very useful supplementary tool. The use of chemicals for weed control dates back many years to the time when copper sulphate, a constituent of the Bordeaux mixture used in vineyards, was found to kill some of the weeds present between the vines. For many years prior to World War II copper sulphate, kainit, and later copper chloride, sulphuric acid, and a number of other materials were occasionally used for the control of weeds in cereal crops. Sodium chlorate and arsenic compounds were also used for gravel paths and patches of land where all vegetation was intended to be killed. In the middle 1930's experiments were being carried out with DNC,[1] but it was not until 1942 that Templeman discovered MCPA [2] at the same time

[1] Dinitro-ortho-cresol.
[2] 2-methyl-4-chloro-phenoxy-acetic acid.

that 2.4-D[1] was being discovered in America. These growth-regulating herbicides were being used commercially by 1946, and by 1952 over 2½ million acres were sprayed in Great Britain for weed control, much of it with these materials. This research and rapid development has now made it possible to control a range of weed species in a large number of the crops grown in Britain.

Classification of Materials.—The scope of chemical weed control has widened to such an extent that it is more than ever necessary to have some understanding of the way in which the different types of chemicals act on plants. This is, in fact, an understanding of the factors on which selectivity and toxicity depend, and it should enable one to group many of these substances in a logical manner according to their manner of action and use.

It is necessary to distinguish between those chemicals which are *non-selective* in their action and those which are *selective* as between different plant species or groups. Selectivity is usually a matter of degree: it is seldom complete in the sense of killing one species and leaving another entirely unaffected.

Non-selective herbicides may act entirely upon the leaves—some oils are toxic in this way—and kill all tissues with which they come in contact. Alternatively, the chemical may act through the root system, killing those plants which absorb sufficient of it. The relatively insoluble compounds of arsenic and boron act in this latter way. The soluble sodium arsenite is also a non-selective herbicide but can act through the leaf, as well as later through the roots if a sufficient amount is used. Applied in sufficient quantity to the soil, arsenic can act as a "permanent" soil sterilant, preventing the growth of plants for many years. This sense of the word "sterilization" should not be confused with others; for example, the term is also applied to the effect of steam or chemicals upon the soil microflora.

Sodium chlorate can act non-selectively as a temporary soil sterilant: temporary because it is broken down in the soil in a period of six to twelve months. Sprayed as a solution on to plants, chlorate can, however, show some selectivity, the degree depending on how much of the spray solution is retained on the leaf. A waxy grass leaf will shed most of the spray, whereas a flat and hairy leaf will retain some of the liquid.

[1] 2-4-dichlor-phenoxy-acetic acid.

Selective action in a herbicide is a feature of great value to the farmer and market gardener; in this context it means no more than that one species (the crop) is affected little or not at all, while another (the weed) is damaged or killed. A herbicide may act in a selective manner when applied as a "pre-emergence" treatment, *i.e.* the weed is treated before the crop seedlings emerge. A considerable range of chemicals can be used in this way provided they have no harmful "residual" effect upon the crop seedlings emerging later on. Perhaps the most familiar example is the sulphuric acid pre-emergent treatment of onions. However, a number of materials, including some tar acids and light oils, can act in a similar manner; for instance, tractor vaporising oil is toxic to a wide range of seedling weeds but has little residual toxicity. Pre-emergent weed control may also be achieved in a slightly different way: a *fortified* oil (*viz.* diesel oil with PCP [1] or DNC) may be applied before the crop emerges. This will not only kill such seedling weeds as are present but the fortifying agent will have a lasting effect. Provided conditions are suitable, the weeds which continue to germinate near the soil surface will be killed while the crop seedlings, emerging from a greater depth, will be unharmed. This principle is well established, but its application to crops in this country was very limited at the time of writing.

Selectivity is more commonly manifest to-day in the spraying of cereals, peas, grassland, etc., when both crop and weed receive some of the spray (or dust) containing the herbicide. In this case selectivity between crop and weed will depend on one or more, and usually several, of the following factors:—

(*a*) Differential retention of herbicide on the plant.
(*b*) Degree of penetration into the leaf or other aerial parts.
(*c*) Translocation within the plant.
(*d*) Physiological effect at the site of action.

Retention of the material will obviously depend on such factors as shape and position of the leaf (broad and flat, or narrow and upright), the hairiness of the leaf and the nature of its surface (waxy or otherwise). If the herbicide is retained on the leaf surface, a variable amount may penetrate into the tissue through the cuticle or stomata.

[1] Penta-chlor-phenol.

Having penetrated into a leaf the chemical may or may not affect the rest of the plant, this depending on whether it is translocated within the plant.

Finally, the chemical may have no effect upon the species even though it is absorbed (*i.e.* it is non-toxic to that species), or it may have an effect upon some aspect of the plant's metabolism with a consequent damaging effect on growth. The " site of action " may be the cells of the leaf, the respiratory system, or some other part of the plant's system. The precise manner in which many of the herbicides act upon plants is still actively engaging many research workers, for it will only be through an understanding of these processes that new chemicals and new techniques will be evolved.

The More Important Chemicals.—There are so many substances with known herbicidal effects that only a small proportion can here be listed, mainly those already in common use or showing promise for the future. Full instructions regarding the field use of the materials can be obtained from books or instruction manuals devoted to this subject.

(*a*) NON-SELECTIVE.—*Oils.*—Many of the unsaturated and aromatic hydrocarbons are toxic to plants when applied to the foliage. These include some of the lighter petroleum fractions (*viz.* diesel or gas oil, and some paraffins) and many of the tar oil fractions. These or other less toxic but equally penetrating oils may be fortified with such materials as PCP, DNC, or DNBP [1] to increase their effect upon the plant. The oil spreads over the leaves and assists penetration of the toxic fortifying chemical, thus preventing the (selective) principle of " differential retention " from operating; hence the spray becomes virtually non-selective in its action. Oils seldom have any lasting effect upon the soil or on the subsequent growth of plants when used in the usual modest quantities—less than about 100 gals. per acre.

Arsenic.—Arsenic compounds are not only poisonous to humans but, when present in the soil in sufficient amount, can prevent the growth of plants for a considerable length of time, possibly many years. Frequently of low solubility, the compounds become " fixed " in the soil and are then removed only very slowly. The period of sterility will depend on the quantity of arsenic used, the soil type, and the rainfall. There are only slight variations in susceptibility between plant species. Rates

[1] Di-nitro-ortho-secondary-butyl-phenol, now termed dinoseb.

of up to 6 cwt. per acre of arsenic trioxide (As_2O_3) or the equivalent in other compounds may be used for soil sterilization. The soluble sodium arsenite—used for potato haulm destruction—may be partly absorbed through the leaves, but will also act through the roots if it is applied in sufficient amount. The arsenite will decompose in the soil fairly quickly and can then cause some degree of sterilization.

Boron.—Borax is chiefly known in British farming as being necessary, on some soils, as a plant nutrient. It is seldom used as a herbicide. In sufficient quantity, however, it can act in a manner very similar to arsenic, being highly toxic to plants. An application as low as 30 lb. per acre to a non-sensitive crop such as sugar-beet has been known to cause toxic symptoms during the following year in a boron-sensitive crop such as potatoes. In America borax is sometimes used for soil sterilization at rates of up to 6 cwt. per acre. It is preferred by some, because it is safer to handle than arsenic and has none of the fire hazard associated with sodium chlorate.

Sodium Chlorate.—At times sodium chlorate has been relatively cheap and easy to obtain and it has been used in a variety of ways. Used in preference to the less soluble ammonium and potassium chlorates for weed-killing and potato haulm destruction, sodium chlorate has one great drawback—it is extremely inflammable when dry: in fact, a serious explosion can be caused if a keg of chlorate is exposed to sufficient heat or to a flame. Sprayed foliage and clothing, wetted with chlorate solution and afterwards dried, can be very inflammable. Because of this, non-inflammable formulations, such as Atlacide, have been developed. These usually consist of a mixture of sodium chlorate and a hygroscopic agent such as calcium chloride. Sodium chlorate has been used as a selective herbicide in grassland at rates of 50 to 70 lb. per acre in 100 gals. of water (5 to 7 per cent. solution). The degree of selectivity, however, is not great, and some scorch damage to the grass is often experienced. As a temporary soil sterilant for the eradication of patches of perennial weeds such as couch, nettles, etc., rates of 3 to 5 cwt. per acre[1] have been used, the precise amount depending on soil type, rainfall, and the effect desired. This is applied dry to the soil surface during the spring or early summer. In normal conditions the treated area can carry a crop after the next winter's rains have removed the last

[1] Equal to 1 to 1·6 oz. per sq. yd.

traces of the chemical. Sodium chlorate can be absorbed by both leaves and roots of plants.

CMU (*p*-chloro-phenyl-dimethyl-urea).—Research has shown that some compounds of the group known as substituted ureas, of which CMU is one, have considerable phyto-toxic properties. Nearly insoluble in water and in most organic solvents, CMU is toxic at very low rates per acre to most plants. Since it is only slightly soluble and breaks down in the soil fairly slowly, it has considerable promise as a temporary soil sterilant. At suitable rates it may also have a use as a selective pre-emergence material, but experience at the time of writing was too limited to say more than that the chemical showed promise.

(*b*) SELECTIVE.—*Oils*.—Although many oils are non-selective in their action, a few fractions have been found to have valuable selective properties. These are the " white spirits " which are used for the control of seedling weeds in umbelliferous crops such as carrots, parsley, and parsnips. Certain paraffin fuel fractions, such as are used for tractors, may have similar selective properties, and with certain precautions can be used in this way. Rates are between 40 and 80 gals. per acre, depending on crop, weed, and weather conditions. The oil must not be mixed with water or spreaders or emulsifiers since its selective properties would be destroyed if this were done.

Copper Salts.—Copper sulphate is hardly ever used to-day for weed control since more efficient and less corrosive materials are available. Copper chloride is a rather more effective herbicide for use in cereals but is relatively expensive; it is seldom used to-day except—and then only occasionally—in under-sown cereals, when it has the advantage of causing relatively little damage to the clovers. Rates used are from 10 to 30 lb. of the salt in 100 gals. of water to the acre, depending on the weed and the crop.[1] These copper salts are extremely corrosive to the metal parts of most spraying machines, even more so than sulphuric acid.

Common Salt.—This has been used for spraying such easily controlled weeds as charlock seedlings in sugar-beet and mangold crops. Rates employed are of the order of 250 to 300 lb. in 150 gals. of water per acre. The treatment is variable in its effect according to weather and other factors and could not, at the time of writing, be generally recommended. Nitrate of soda has been used in a somewhat similar manner.

[1] Copper chloride was almost unobtainable at the time of writing.

Sulphuric Acid.—Despite the dangerous nature of this chemical, if allowed to come into contact with the skin or with clothing, it is still favoured by many as being one of the most efficient in checking the growth of a " winter proud " wheat crop. It is relatively cheap and kills a very wide range of weeds. Its use is limited not only by the fact that it is dangerous to handle but also by the fact that special machines are needed. Sulphuric acid is available commercially as BOV (Brown Oil of Vitriol), which contains approximately 70 per cent. of the pure acid. BOV, since it has no residual toxic effect, may also be used as a pre-emergence herbicide. It is rendered harmless within about an hour, following chemical reaction with the soil or the plant tissue. Rates of application range from 10 to 16 gals. per acre, and it may be applied either diluted with water or, in some circumstances, undiluted.

The Dinitro Compounds.—The two important members of this group are DNC (di-nitro-ortho-cresol) and dinoseb[1] (di-nitro-ortho-secondary-butyl-phenol). Although poisonous to human and animal life, these herbicides are widely used to-day. DNC is used in cereals either as the free acid, the ammonium or sodium salt, or as the " activated " acid. The acid is relatively insoluble in water and is therefore used as a suspension; the salts are rather more soluble. DNC should be used only in spraying machines equipped with thorough agitation to keep the material mixed; it is not used as a dust. Although the range of weeds controlled is not so wide as with sulphuric acid, DNC controls a rather wider range than the growth-regulating herbicides MCPA and 2.4-D—especially the "difficult" species such as cleavers and mayweeds. Furthermore, DNC can be used, with certain precautions, on all cereals, whereas sulphuric acid cannot. Dinoseb, developed after DNC, is used widely on peas, increasingly on lucerne, and to a small extent on beans and seedling clovers. Usually the insoluble ammonium salt is formulated in an organic solvent so that it can be mixed with water for application as a " solution " to the crop. Broadly, a similar range of weeds is controlled to that controlled with DNC. Both DNC and dinoseb act as " contact " herbicides, affecting the cells of the leaf and growing point and causing a complete collapse. They are not translocated and hence are of value in the control of annual weeds only. A uniform cover is

[1] Formerly known as DNBP.

essential, and for this reason both are applied at high-volume rates, at least 60 gals. and, usually, 80 to 100 gals. per acre. Normal rates are 6 lb. per acre for DNC and 1¾ to 2 lb. per acre for dinoseb. Rates of dinoseb are usually varied with the growth of the crop and the temperature conditions—the higher the temperature, the lower the safe rate.

Both DNC and dinoseb are yellow-staining compounds and are highly toxic if absorbed into the human body. Recognized precautions must be observed in their use.

Growth-regulating Herbicides.—These include: (1) MCPA (2-methyl-4-chloro-phenoxy-acetic acid), (2) 2.4-D or DCPA (2-4-dichlor-phenoxy-acetic acid), and (3) 2.4.5-T or TCPA (2-4-5-trichlor-phenoxy-acetic acid). Fundamental research into the function of substances which control the growth processes of plants achieved most valuable practical results in the development of these herbicides. They are not "hormones" in the proper sense and are best described as "growth-regulating substances." Depending for their action first on absorption by leaves or roots, they can be translocated and may have an effect upon the plant metabolism. Because they act in this way, they can be used to control a considerable range of perennial weeds as well as susceptible annuals. Furthermore, they may be applied in low volume (5 to 20 gals. per acre) as well as at high-volume rates. This is possible because of their manner of action, since it is unnecessary to secure full coverage but only to ensure that sufficient herbicide is absorbed through the leaf or some other part of the plant. Some formulations may be applied in the form of dusts. Rates vary according to the crop, the weed and the precise formulation, but are generally between ½ and 2 lb. per acre of the active ingredient, this being usually measured in terms of the "acid equivalent."

MCPA and 2.4-D are widely used on cereals and grassland, their selectivity being chiefly between monocotyledons and dicotyledons. Precautions have to be taken with their use on cereals, since, if applied at too early a stage of growth, they may cause disorders in the later growth of the cereal. Annual weeds are most easily controlled by treatment at an early stage of growth; the younger the seedling, the better the control. Perennials are generally best treated at a later stage of development, usually at the flower-bud stage.

The forms in which these herbicides are available commercially

are as follows. The precise formulation for marketing can vary in each case :—

MCPA—Sodium, potassium, or amine salt, frequently as 25 to 40 per cent. w/v liquid concentrate, but also 1 or 2 per cent. dusts.

2.4-D—

(*a*) Sodium salt, usually as a powder for dissolving in water; soluble only at dilutions greater than 1 lb. in 20 gals.

(*b*) Amine salts, readily soluble in water; very commonly used; 50 per cent. w/v concentrates are available.

(*c*) Esters, insoluble in water but supplied in oil, with an emulsifier, for mixture with water.

2.4.5-T is used rarely, but either alone or mixed with 2.4-D it is valuable for the control of certain "woody" weed species. Thus it has been used for the control of scrub growth along rights-of-way, and has been tried as a tree defoliant. It is commonly formulated as an ester.

All these herbicides remain active in the soil for some time before they are broken down by specific soil bacteria. In normal conditions this period is six to eight weeks for MCPA and four to six weeks for 2.4-D. Susceptible crops should not be sown before this period has elapsed.

Other Materials.—IPPC (iso-propyl-*n*-phenyl-carbamate), or IPC as it is sometimes called, is in fact a growth-regulating substance but is excluded from the list above since it functions in a very different manner. Whereas MCPA and 2.4-D are toxic to broad-leaved plants and less so to the cereals and grasses, IPPC acts more nearly in the opposite fashion, being, in particular, toxic to seedling grasses. At the time of writing, a suitable technique for its use as a herbicide had yet to be developed. Interest had, however, been aroused in it because of the possibility of its controlling wild oats in crops other than cereals.

Chloro-IPC is a similar chemical which was under trial for the control of weeds in strawberries.

TCA (trichloracetic acid). All the chlorinated acetic acids are phytotoxic in some degree; for instance, the mono-chlor derivative has been used as a defoliant. TCA is the most toxic and is usually sold as the sodium salt, a white crystalline substance which goes yellow on exposure to damp.

TCA is especially toxic to grasses and is used to some extent

for the control of couch and allied weed species. It is mainly root-absorbed and, therefore, for maximum effect, needs to be worked into the upper layer of the soil. Its selectivity is not such as to allow its use in the presence of broad-leaved crop plants, but in certain circumstances such crops can be sown before the full residual effect of the TCA has been dissipated from the soil. It is usual to combine the application of TCA, in early summer, with subsequent cultivations. At the date of writing suitable techniques had yet to be developed for the commercial use of TCA in Britain. Rates being used ranged from 30 to 90 lb. per acre.

PCP (penta-chlor-phenol). Usually available as the sodium salt, this chemical is toxic to a wide range of plants, and in some ways to man. In 1953 it had been used in Britain only experimentally, but it seemed that its main use might be in pre-emergence weed control. Since it is very stable its toxicity persists in the soil until it is leached out. Dose rates are from 4 to 8 lb. per acre.

Cyanamide. This chemical has been used on the Continent for many years as a combined nitrogenous fertilizer and herbicide for cereal crops. In Britain the use of the material has never developed on a considerable scale, nor does it appear likely to do so. This is explained partly by the recent development of more efficient herbicides and partly by the difficulty of obtaining supplies for agricultural purposes.

Use on Crops.—Apart from the wide range of crops which may be treated by pre-emergence applications, there are very many which can be successfully treated after emergence with selective herbicides. The following tables (pp. 164 and 165) list the more important of these, with the approximate amounts of the various materials that may be used in each case.

Precautions.—Stress has already been laid on the fact that with most weed and crop associations the selectivity between the two is often a matter of relative toxicity at the rates used; in other words, selectivity is not absolute. If selectivity were complete the problem in the field would be much simpler than it is.

Many crops can be damaged by a comparatively small overdose. The damage, in the case of DNC and dinoseb, takes the form of excessive scorch. A too early or too late application of MCPA or 2.4-D to cereals can cause deformed growth, and

Weed Guide

List of Common Weeds and their Response to Appropriate Applications of Weed Killer

English Name	Latin Name	MCPA	2,4-D	BOV	DNC	Dinoseb	Mineral Oil
Annual meadow grass	*Poa annua*	R	R	...	..	.	s
Bindweed, black (s) .	*Polygonum convolvulus*	s	s	S	s	s	s
Bindweed, black (o) .	*Polygonum convolvulus*	R	r	S	s	s	s
Bindweed, bellbine .	*Convolvulus arvensis*	r	s	R	R	R	R
Buttercup, corn .	*Ranunculus arvensis*	S	S	r	r	r	.
Buttercup, bulbous .	*Ranunculus bulbosus*	r	r	R	R	R	R
Buttercup, creeping .	*Ranunculus repens*	S	s	R	R	R	R
Bracken . . .	*Pteridium aquilinum*	R	R	R	R	R	R
Charlock, yellow .	*Sinapis arvensis*	SS	SS	SS	SS	SS	SS
Cleavers; Herrif .	*Galium aparine*	R	R	S	s	s	
Chickweed . .	*Stellaria media*	r	r	s	s	s	S
Coltsfoot . .	*Tussilago farfara*	r	r	R	R	R	
Cornflower . .	*Centaurea cyanus*	s	s	r	s		
Corn marigold .	*Chrysanthemum segetum*	R	R	r	s	r	
Dock, broad-leaved .	*Rumex obtusifolius*	R	R	R	R	R	R
Dock, curled-leaved .	*Rumex crispus*	r	r	R	R	R	R
Dock seedlings .	*Rumex spp.*	S	S				
Dandelion . .	*Taraxacum officinale*	s	s	R	R	R	R
Daisy, ox-eye . .	*Chrysanthemum leucanthemum*	r	r	R	R	R	R
Fat hen (s) . .	*Chenopodium album*	S	S	S	S	S	S
Fat hen (o) . .	*Chenopodium album*	s	s	S	s	s	s
Fumitory . .	*Fumaria officinalis*	s	s	S	S	S	.
Gromwell, corn .	*Lithospermum arvense*	r	s	S	S	S	.
Groundsel . .	*Senecio vulgaris*	r	r		s	s	
Hemp nettle (s) .	*Galeopsis tetrahit*	S	r	S	S	S	S
Hemp nettle (o) .	*Galeopsis tetrahit*	s	R	S	S	S	.
Horsetail . .	*Equisetum arvense*	s	s	R	R	R	R
Horsetail, marsh .	*Equisetum palustre*	(tops) s (only)	s	R	R	R	R
Heartsease . .	*Viola tricolor*	s	r		r	r	
Hoary pepperwort .	*Cardaria draba*	s	s	R	R	R	R
Knotgrass . .	*Polygonum aviculare*	r	r	s	r	.	.
Mayweed, scentless .	*Matricaria inodora*	r	r	S	s	r	
Nettle, annual . .	*Urtica urens*	r	r	s	s	r	r
Nettle, stinging .	*Urtica dioica*	r	r	R	R	R	R
Pennycress . .	*Thlaspi arvense*	SS	SS	SS	S	S	S
Poppy (s) . .	*Papaver rhoeas*	s	s	S	S	s	
Poppy (o) . .	*Papaver rhoeas*	r	r	S	S	s	
Persicaria (s) . .	*Polygonum persicaria*	s	s	s	r	r	.
Persicaria (o) . .	*Polygonum persicaria*	r	r	s	r	r	
Runch (s) . .	*Raphanus raphanistrum*	SS	S	S	S	s	
Runch (o) . .	*Raphanus raphanistrum*	S	s	S	S	s	
Rush, common .	*Juncus effusus*	S	S	R	R	R	R
Shepherd's purse .	*Capsella bursa-pastoris*	S	S	S	S	S	s
Shepherd's needle .	*Scandix pecten-veneris*	s	r	s	s		
Spurrey (s) . .	*Spergula arvensis*	s	s	s	s	r	S
Spurrey (o) . .	*Spergula arvensis*	r	r	s	s	r	S
Speedwell, ivy-leaved	*Veronica hederifolia*	s	r	S	S	s	s
Sowthistle, annual (s)	*Sonchus oleraceus*	s	s	.	r	r	...
Sowthistle, annual (o)	*Sonchus oleraceus*	r	r		r	r	..
Sowthistle, perennial	*Sonchus arvensis*	s	s	R	R	R	R
Thistle, creeping .	*Circium arvense*	s	s	R	R	R	R
Thistle, spear . .	*Circium vulgare*	s	s	R	R	R	R
Treacle, mustard .	*Erysimum cheiranthoides*	SS	SS	SS	S	S	S
Wild onion . .	*Allium vineale*	r	r	R	R	R	R
Wild oat, spring .	*Avena fatua*	R	R	R	R	R	R
Wild oat, winter .	*Avena ludoviciana*	R	R	R	R	R	R
Wild carrot . .	*Daucus carota*	r	r	..	...	...	...

KEY

(s) = Seedling.
(o) = Older plant.
SS = Very susceptible.
S = Susceptible.
s = Moderately susceptible.
r = Moderately resistant.
R = Resistant.

CROP GUIDE

Summary of the Principal Weed Killers and Crops to which they may be Applied

Crop	MCPA Sodium, Potassium, or Amine	2.4-D Amine	2.4-D Ester	BOV Sulphuric Acid	DNC [1]	Dinoseb [1]	Mineral Oil
Winter							
Wheat	†	†	†	†	†	2	...
Barley	†	†	†	2	†	2	...
Oats	†	†	†	2	†	...	...
Rye	†	†	†	†	†	...	...
Spring							
Wheat	†	†	†	2	†	...	...
Barley	†	†	†	2	†	...	...
Oats	†	...	...	2	†	...	...
Peas, beans, and lucerne	3	...	...	...	...	†	...
Flax and linseed	†	...	...	...	4	...	...
Carrots, parsnips, and parsley		...	...	...	...	...	†
Onions and leeks	...	...	...	†	...	...	...
Kale	...	...	...	2	...	...	...
Clovers, red and white	...	...	...	...	...	2	...
Asparagus	...	...	...	...	...	...	...
Permanent grassland	†	†	†	...	...	...	...
Seedling grasses	2	2	2	2	2	...	...

† - Safe application provided manufacturer's recommendations are followed.
1 - Poisonous substance; its use must conform to the provisions of the Agriculture (Poisonous Substances) Regulations, 1954.
2 - May be used in special circumstances; seek expert advice.
3 - MCPA dusts may be used on peas in certain circumstances.
4 - DNC *sodium* salt only.

affect seed formation in various ways. Again, normal cultivations near the time of spraying may injure a crop sufficiently to allow entry of a herbicide into the leaf, with possibly harmful consequences. Disease of the crop may render it more easily affected by the treatment. All these factors have to be considered in the application of herbicides in the field.

Some of the chemicals are dangerous to handle, and in such cases operators must have careful instruction and close supervision.

Weed Species.—The choice of a particular herbicide for a particular purpose will depend firstly on the crop and secondly on the particular weeds present. The various herbicides differ in the range of weed species which they can control. Sulphuric acid controls the widest range of annuals; DNC probably comes next among the more commonly used chemicals, followed in turn by MCPA and 2.4-D. The last two, however, also control a range of perennials. Examples of these differences may be seen with such "difficult" species as cleavers, mayweeds, corn marigold, and corn buttercup. The first three are controlled by DNC far better than by MCPA or 2.4-D; the growth-

regulators are ineffective against these three, but do control corn buttercup far better than does DNC.

There is some evidence from America that the regular use of a single type of herbicide may lead to the evolution of strains of weeds which are resistant to the material in question. Cases quoted have included Johnson grass (*Sorghum halepense*) under treatment with TCA, and Creeping Thistle (*Circium arvense*) with 2.4-D. It is commonly believed that the use, in rotation, of two or more herbicides may avoid this danger, provided, of course, that the alternatives adequately control the weed flora as a whole.

Details of the weed species controlled by the various herbicides may be obtained from Ministry of Agriculture Advisory Leaflets and certain manufacturers' published recommendations. It must be borne in mind that the whole subject was still in rapid development at the time of writing.

CLEANING OPERATIONS

The Bare Fallow has the primary object of cleaning the land, but it is usually carried out in such a way as to prepare a seed-bed for an autumn-sown crop, generally wheat. The bare fallow area in Britain has progressively declined with the development of other methods of weed control, and it is now of the order of only 2 or 3 per cent. of the total under tillage. Fallowing is, however, still a normal practice on arable clay land in the hotter and drier parts of England. The following description applies to these particular conditions.

The general plan is to keep the soil, during the earlier part of the growing season, in large clods which are turned over at intervals so that they may dry out thoroughly. The stolons of couch-grass, water-grass, and other weeds of similar growth form, are fairly easily killed by desiccation, and even the roots of docks, although they are more resistant to drying, are killed under favourable conditions. Later on, usually after midsummer, the clods crumble under the influence of repeated wetting and drying. If necessary the process is assisted by stirring the land when the clods are moist. A fine tilth is thus produced in which weed seeds germinate freely, and the resulting seedlings are buried by a final ploughing.

The first ploughing should be delayed until the season of frost

is over—*i.e.* until April. Frost occurring after the land had been ploughed would so " mellow down " the furrow-slices that these would shatter when moved. Ploughing should be done when the land is fairly wet, and a long-mould-board plough should be used so that the furrows may be turned with a minimum of breakage. This first ploughing should be as deep as any other in the rotation.

As soon as the greater part of the furrow-slice has dried out, the land should either be cross-ploughed or else deeply cultivated across the direction of the furrows. Steam tackle was at one time used for cultivating, but the task can be equally well done by a powerful crawler tractor. The plough has the advantage that it undercuts practically the whole area, thus severing any thistles, bindweed, etc., that have their runners below the plough depth; this cutting below the surface helps to exhaust the food stores in the root-stocks and thus to weaken the plants. If few such weeds are present the cultivator will serve the purpose equally well. The land will now be, as it should be, in a very rough state, *i.e.* with clods three or four times as large as bricks.

The clods are moved perhaps twice more, by cultivator, during June and July, choosing, as far as possible, hot drying weather for the operation. By harvest time, in an average year, the clods will generally have crumbled to a tilth. If this has not happened, and if it is certain that the twitch, etc., is dead (as can be determined by its shrunken and brittle condition), the breakdown may be hastened by drag harrowing after a good shower.

If all has gone well a good crop of annual weeds will have sprung up by the time cereal harvest is over, when they are destroyed by ploughing them under. Ploughing is to be preferred to cultivating at this stage; partly because the weeds are better put out of the way, but also because cultivating will tend to make a tilth that is too fine for winter wheat, whereas the plough puts the fine mould underneath and brings some clods to the surface. A second growth of annual weeds may spring up, but these will be automatically destroyed in the course of wheat sowing.

It will be obvious that a bare fallow will sometimes fail to do all that is intended. This will happen especially if May and June are wet. In some cases the risk of failure may be reduced by stubble cleaning (see p. 169) in the autumn preceding the fallow.

Fallowing produces some indirect effects that are not fully understood. For example, when parts of the continuous wheat field at Rothamsted are summer fallowed, the yield on the

continuously unmanured plot jumps from something like 13 to about 30 bushels. The effect lasts only one season. No doubt the constant aeration during the fallow stimulates the action of soil organisms and makes available a good deal of soil nitrogen. This is in keeping with the fact that wheat following fallow on fertile soil is often "winter-proud" and runs too much to straw. On poor clay land, however, wheat after fallow usually yields better than after another crop, not excluding clover or beans. Another useful effect of fallowing is a marked reduction of the wireworm population of the land, especially if rooks are plentiful in the area. On the other hand, attacks of wheat bulb fly (see p. 274) are rather common in the succeeding crop.

Light or loamy land that is fairly heavily infested with perennial weeds can generally be cleaned by other and less costly methods than fallowing—*e.g.* by taking a crop of potatoes, planted if necessary as late as May, or by the process of "spring cleaning" in preparation for a late-sown crop of turnips, swedes, or kale. In extreme cases a bare fallow may be made, but naturally the technique must be different, for the reason that light land will not "hold its clod"—unless, indeed, it is bound together by a close network of couch. In the driest districts good results may be obtained by the simple expedient of repeated ploughings, turning the soil over whenever any considerable number of green shoots is to be seen. This process will obviously dispose of large numbers of weed seeds as well as of perennials.

The Bastard Fallow differs from the bare fallow in that operations start later, generally in June. It may be taken after a clover or other ley has been mown, or after an autumn-sown silage crop has been harvested. It is effective, even in dry years, only in areas where there is a long growing season as well as a low rainfall. A frequent initial difficulty is that a heavy soil, in June, may be too hard to be ploughed, and the chance of a sufficient spell of dry weather after June is relatively small. However, the production of a good clover aftermath in the drier parts of the country is comparatively rare, so that the sacrifice of income, by breaking up the hay stubble, is not a very serious matter. On thin soils such as those of the oölitic limestone and the Wolds, where wheat is taken after seeds, there is a further reason in favour of the bastard fallow in those cases where ryegrass is included in the seeds mixture. This is that ryegrass harbours frit fly, which may destroy the young wheat (see p. 274).

The procedure in bastard fallowing is essentially the same as that described for a full fallow, except that the work must be completed in a shorter time. Failures to get a complete kill of twitch are rather frequent.

Cleaning Light Land.—The usual procedure in dealing with light or loamy land that is infested with couch, etc., is to drag the stolons out of the soil. The first operation is to plough with a digger-type implement, going no deeper than is necessary to get underneath the stolons. The depth required is usually about 4 in., but the furrow bottoms should be examined for runners that may lie deeper, and, if any considerable numbers are being missed, the depth should be increased. The land, after having a little time to dry, should next be crossed with a cultivator or drag harrow, running to the full depth of the furrow-slice, which is thus broken. Some couch will be brought to the surface in the process. After the stirred land has dried, or preferably after it has been moistened by rain and again dried, a drag or other heavy harrow is used to shake the couch free of soil, when it is rolled up by a light zigzag or chain harrow and is either burnt in small heaps or is carted off to a compost heap. The land should then be examined and the whole process repeated if necessary. In extreme cases a third repetition may be required. In the case of onion couch, care must be taken to get the soil very loose before dragging is attempted, otherwise the clumps will break up in the process. The further loosening is best secured by cross ploughing.

The operation described may be done either in the spring—*e.g.* in preparation for a crop of roots, kale, or rape—or alternatively in the latter part of summer—*e.g.* after a silage crop or once-cut clover.

It is worth noting that on specially deep soils this laborious business may be avoided altogether by the simple expedient of trench ploughing with a single-furrow tractor plough fitted with a wide skim coulter. The object is to turn the top 4 in. of soil into the bottom of a deep furrow and to cover this with 6 or 8 in. of clean soil from underneath. The following crop should, of course, be roots, kale, or potatoes, since some couch will probably struggle to the surface; but the amount will rarely be more than can be dealt with in the course of routine row-crop cultivations.

Stubble-cleaning.—In this process, as ordinarily understood, no serious attempt is made to deal with perennial weeds. It is true that light land that has carried a crop of winter oats, and may be

cleared by early August, can be dealt with by the process last described. More usually stubbles are not cleared till September, by which date, even in the drier areas, the chance of a sufficient spell of dry weather is too small to encourage the attempt to get couch out of the soil. The object of the operation now to be described is to induce the germination of weed seeds that have been shed before or during harvest. Incidentally, shed grains, which might give rise to "rogues" in a succeeding grain crop, are dealt with at the same time. If the seeds can be induced to sprout, the seedlings will be killed and buried by the normal operation of late autumn or winter ploughing.

What was said earlier (p. 153) about the dormancy or "after ripening" of weed seeds must, however, be borne in mind. If stubble-cleaning operations are carried out in September some seeds will germinate as soon as rain falls, while others will lie dormant until October or November, and still others until the spring. But again it must be remembered that if the previous season has been an early one many of the seeds will have been shed some considerable time before harvest. In general, if the intention is to plough the land in October for winter corn, stubble-cleaning will fail in regard to many particular species. On the other hand, if ploughing can be left over till late November or December good results may be expected.

The actual process is simple. All that is required is to disturb the soil to a depth of about 2 in. The Kentish broadshare was specially designed for the purpose, but almost equally good results can be obtained, if the soil is reasonably moist, by a tractor-drawn cultivator fitted with wide-cutting shares. If the land is dry and hard, a disc harrowing, repeated if necessary, will generally achieve the object.

PREPARATION OF SEED-BEDS

The seeds of our farm crops vary greatly in size, from beans at the one extreme to wild white clover and the meadow grasses at the other. A rather common misconception exists in regard to mangolds and sugar-beet; the material ordinarily sown consists of clusters of several fruits, and the actual seeds are very small.

Large seeds may be sown at considerable depths and therefore in soil which will generally be moist. On the other hand, the smallest may fail to push up to the surface if they are buried 1 in.

deep; hence there is, at the ordinary seasons of sowing, a considerable risk that these will fail to find sufficient moisture for germination.

The moisture for germination, in the absence of water that is percolating through the soil, must come either from the thin film that surrounds the mineral particles (capillary moisture) or from that which is held in jelly-like form by the soil colloids (imbibitional water). It will readily be understood that a seed, in order to take up the moisture that is available in these forms, must be in close, all-round contact with the soil crumbs. Obviously a small seed cannot be in general contact with large clods. Hence it is a general rule that the size of the seed-bed crumb must be closely related to the size of the seed; and again it is a rule that the drier the soil in the zone of the seed the more firmly must the seed-bed be compressed. The fact that the best "take" of clover is often to be found on the headlands of a field illustrates the importance of compaction.

Seeds, however, may be sown in autumn, spring, or summer, and therefore under very different moisture conditions; hence, quite apart from the size of seed and the particular requirements of the crop, autumn, spring, and summer tilths should differ in structure. At the one extreme, wheat may be sown in November when the soil is quite wet—too wet for a drill to run clean. Spring cereals are usually sown about as soon as the lower soil is dry enough to carry tractors and implements without damage, and when, therefore, there is plenty of moisture at the depth of 2 or 3 in. at which the seed is sown; here, however, the farmer must think of the later moisture requirements of the young seedlings, which may be imperilled if the tilth is rough. At the other extreme, land that has been repeatedly worked in a dry May is likely to be so dry that a very fine and very firm tilth is required to ensure germination.

Autumn Seed-beds.—Many grasses are quite frost-hardy in the seedling stage and might be sown in autumn but for the fact that their hardiness is not shared by the clovers. In British practice, autumn sowing is restricted to frost-hardy varieties of beans, vetches, and the four cereals.

In order to arrive at the principles of autumn seed-bed preparation, we may consider separately the various hazards to which the plants are exposed between seed-time (say October) and the following April, when active spring growth ordinarily begins.

The first danger is "throwing out"—*i.e.* loss of roothold. This is caused by the "heaving" of the soil, while it is wet, under the influence of alternating frost and thaw. Soils of high humus content are most apt to heave, and sandy soils least so. In order to minimize the risk of throwing out, the zone of soil below the seed should be firm. The farmer tests for "hollowness" by pressing on the soil with his heel. Again, wireworms are more destructive of winter than of spring grain (because the former has to meet both an autumn and a spring attack), and damage from wireworms is minimized by compaction of the layer in which they work.

Next, autumn-sown corn may be winter-killed, and one frequent cause is the drying-out of the plants by wind during periods when the soil is frozen and when, therefore, no moisture is available to the roots. A smooth surface, such as would be produced by rolling, would obviously give maximum exposure to wind, whereas a rough surface with sizeable clods provides a considerable amount of shelter. Again, if a fine surface tilth is prepared in autumn, the soil, if it contains much clay or silt, will be puddled by rain, and, in the absence of subsequent frost, will dry out in spring with a hard "cap." A continuous crust may reduce soil aeration and hence root activity, and prevent the effective harrowing of the surface in spring (which may be required in order to destroy weeds), or the preparation of a satisfactory tilth for undersown seeds. No harm will come to the cereal if many of the surface clods at the time of sowing are as large as cricket balls and half bricks, so long as there is a layer of reasonably fine crumb around the seed.

The necessary firm bottom may be obtained (*a*) by ploughing the land several weeks before seed time, so that the furrow may settle down, providing what is called a "stale furrow"; (*b*) by furrow pressing, which is desirable in most cases where the wheat follows a ley; and (*c*) in cases where ploughing is done late—*e.g.* after potatoes or sugar-beet—by setting the plough to a slight depth—say 4 in. Repeated harrowings would, of course, consolidate the lower layers, but would in many cases do so at the expense of producing too fine a surface tilth.

If the surface is to be kept rough and cloddy it will be obvious that the use of any form of roller should be avoided, and that the use of harrows should be restricted to the minimum required to produce the small amount of crumb that is required. Heavy harrows with a small number of teeth (semi-drags) produce the

desired amount of compression with a relatively small clod-breaking effect, the harrowing, of course, being repeated until there is a tolerable amount of crumb. The desired arrangement (of clods above the crumb) is automatically brought about by harrowing because, when the mixture is disturbed, the smaller material slips down between the larger. In a typical case three strokes with the harrows will produce a suitable tilth. If the furrow-slices are tough a disc harrow will prove very helpful.

The surface clods, with a normal amount of winter frost, will be well weathered by the spring and, on harrowing, will break down into a fine mould.

Seed-beds for Spring Grain.—The chief weather hazard to spring cereals, apart from a wet harvest, is drought in May and June; this has little or no effect on autumn-sown crops, which are by that time deeply rooted. In order as far as possible to ensure a supply of moisture to the plants at the time in question the seed-bed must be made firm and rather fine. In general this condition will be most readily obtained, on the heavier sorts of soil, if the land can be ploughed, with an unbroken furrow, before Christmas. If this can be done the farmer may hope that frost will do most of the work of seed-bed preparation. Land in old grass, or in two- or three-year-old ley, should be ploughed early even if the soil is light, since it takes time for the turf to decay and for contact to be established between the furrow-slice and the subsoil. If ploughing has been late, a heavy disc should be used (as well as the harrow) in working up a tilth, in order to eliminate the spaces under the furrows. If the cereal crop is to follow sugar-beet or an early-carted crop of roots, ploughing may still be done in time to take advantage of the action of frost. The chief difficulty occurs after late roots, especially if carting has taken place under wet conditions. In this last case the soil will have been puddled in places and the wheel-marks and trackways will show up on the ploughed land as lines of intractable clods. In most such cases it will be desirable to run along the trackways with a disc harrow—perhaps two or three times—and then to disc the whole field. Apart from its use as a clod-cutting tool the disc has a marked compressing effect on the soil, which is especially desirable if the soil is liable to become "puffy."

In a great many cases harrowing alone will suffice to produce the required tilth, but on land where two or three strokes would be enough for winter wheat, six may normally be required for spring

corn. On ploughed-up grassland the first double stroke should be done in the direction of the furrows, otherwise the slices may be pulled apart or inverted.

After drilling, the surface is smoothed by a light harrowing and is afterwards rolled, either at once or at any time (except when the first shoots are very turgid and tender), until the young plants are 2 or 3 in. high. At one time repeated heavy rolling was the only known method of mitigating wireworm damage, but a much better preventive is now available—viz. seed dressing with B.H.C. dust. The consolidating action of even a heavy roller does not extend much below 3 or 4 in., and compression below that level must be secured by means of harrows or discs.

As regards the particular requirements of the different cereals, the only important point is that barley, especially if sown rather late, requires a finer and firmer bed than the others. The reason is that irregular germination of oats or of spring wheat is no very serious matter, whereas if some grains of barley fall among clods and fail to germinate until rain falls, the crop at harvest time will contain green ears, and the sample will be unsuitable for malting. Apart from this point some barley growers cross-plough their land, with a shallow furrow, as part of the tilth-making process. This is a sound procedure in cases where beet-tops or turnip-tops have been ploughed in, since these must be well distributed through the soil in order to produce a uniform crop. Otherwise there seems to be no clear evidence that a second ploughing is beneficial.

One temptation to be resisted, especially in a late spring, is that of starting operations before the lower soil is sufficiently dry to carry the horses or tractors. The top 2 or 3 in. may be in condition to crumble readily under the harrows while the lower soil is still so wet that it puddles under pressure. A little experience will enable anyone to judge, by the depth of the horse's hoof-marks or of the tractor wheel-marks, whether damage is being done. A field rarely dries out uniformly, and it often happens that some parts will be workable when others are still too wet below.

When land has been used for spring folding, and operations therefore start very late, the soil may be so dry that special precautions are necessary to ensure germination. This is best done by dealing with the field piecemeal—*i.e.* ploughing, disking, harrowing, and drilling in quick succession, even to the extent of completing each portion in a single day.

Seed-beds for Small Seeds.—Grass and clover seeds, when

undersown in a spring cereal (which is the commonest practice), present no very difficult problems in the cooler and moister parts of the country. The usual procedure is to broadcast the seed, harrow with a light zigzag or chain-tooth harrow, and roll. This may be done soon after sowing the corn, or alternatively after the cereal is up, and firmly enough rooted to bear harrowing. In the drier parts of the country, where risk of failure is greater, the grass seed should be sown at the earlier opportunity rather than the later, and should be drilled rather than broadcast.

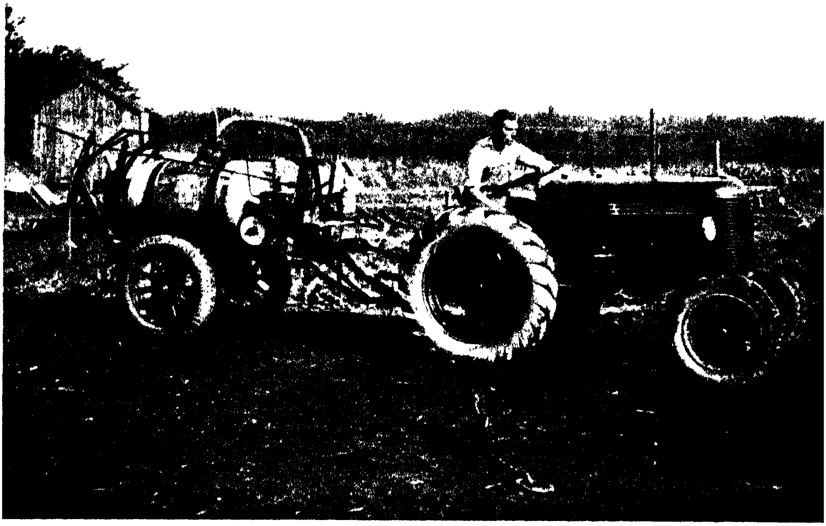
The undersowing of autumn-sown cereals may present an easy or a very difficult problem. After a dry and frosty winter, and especially when frosts occur in late February and March, the farmer may be presented with a ready-made tilth. If, however, the winter is wet and March is dry and frostless the surface will be " capped " and, if the soil is a heavy one, may be so hard that harrows will fail to bite. The situation may be greatly changed by a good shower and any opportunity so created must not be missed. A disc drill, weighted as necessary, may cut into the surface sufficiently to bury the seed. On the heavier soils, however, the chances of failure are considerable.

Root crops are ordinarily sown from March to June, and the seeds must be placed at a slight depth—something like 1 in. It will thus be obvious that the seed-bed should be both very firm and " as fine as oatmeal." But the farmer's problem may be complicated by the facts that the crop is to have a dressing of dung and that operations are required to get rid of couch and other stoloniferous weeds. Let us first suppose that the land is tolerably clean, and that dung is to be ploughed in. The carting of the dung must be done when the soil is either dry, as it may be in October or even November, or else later when it is frost-bound. Carting when the land is wet—unless the soil is a sandy one—will create great difficulties later on. The manure having been spread, the land should be deeply ploughed. If this is done in the early winter it will be worth consideration whether cross-ploughing, at much less depth, should be done in late February or early March. If there is a second ploughing it must be shallow, so as to avoid burying the "frost mould," and should be done early enough to ensure that the fresh surface will in turn benefit from frost. Whether ploughed once or twice, the subsequent formation of a sufficiently fine seed-bed, with the smallest number of operations and consequently the least exposure to the drying action of

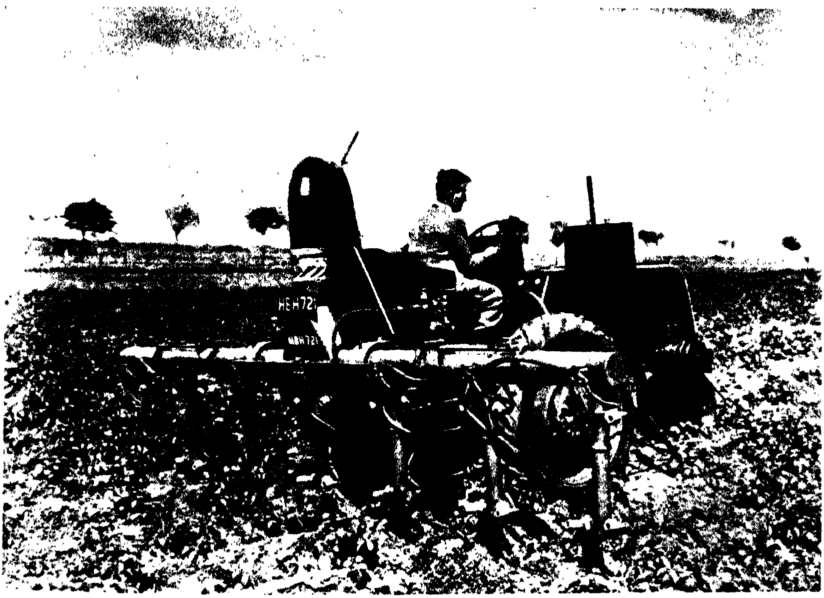
the air, can best be secured in March and April by working the land when it is in a half-dry, friable condition after rain. Half a dozen well-timed operations may achieve success under these circumstances where thrice that number, ill-timed, may fail. The general plan should be to deepen the tilth by successive steps rather than to bring large clods of raw soil to the surface, as will happen if heavy cultivators or grubbers are used in the early stages. After one or two preliminary harrowings the cultivator or drag, the harrow and the roller may be employed, the one following the other. This threefold operation is repeated as often as necessary—up to three or four times—the cultivator being set a little deeper at each successive round. The effect of repeated harrowings, as already explained, is to bring the larger clods to the surface where they may be crushed by the roller. On heavy land in dry seasons, however, the roller may fail to reduce the clods below the size of walnuts or marbles, which is, of course, far too large. In this case a possible solution is to invert the soil with the plough and to harrow, roll and sow immediately.

Land intended for roots that is infested with couch, etc., requires special treatment, but the particular methods to be employed vary with local conditions. For example, light land in the earlier and drier areas may be cleaned (by the method described on p. 169) in the autumn—*e.g.* after the harvest of the preceding cereal crop. Dung will then be spread and ploughed in during the winter, and the tilth prepared as described above. In the north, root crops are commonly grown on ridges and the dung may be applied in the ridge just before sowing. In this case cleaning operations can be done in the spring. Badly infested heavy land will generally require a " half-fallow " in spring despite the fact that this will imply a late crop of roots or kale, sown in June or even July. The spring cleaning of heavy land for mangolds or beet is generally impracticable, since the crop should be sown, at latest, in early May.

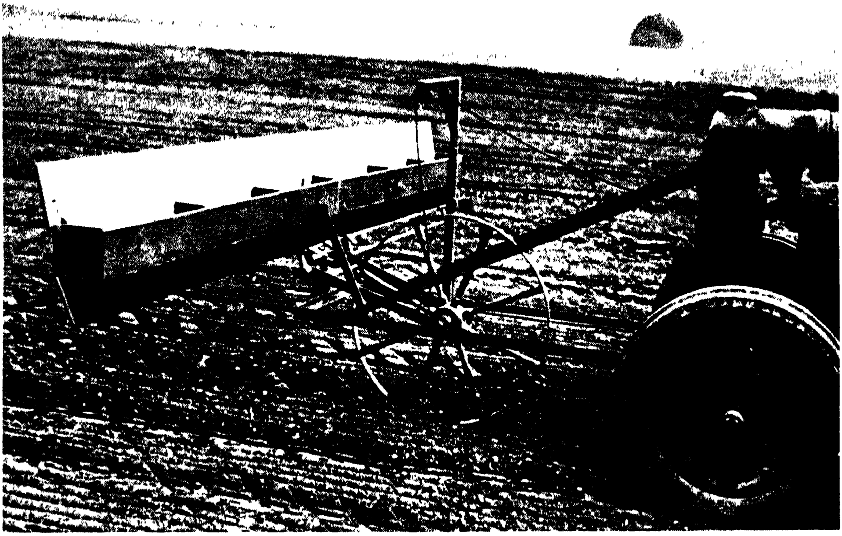
Potato Tilths.—Potato tubers do not require moisture to enable them to sprout, and in any case are placed deep enough to be out of danger from ordinary drought, if only there is some reasonably fine mould below the sets. The object, therefore, is to produce a deep and *loose* tilth, and there is no need to keep the " frost mould " on top—indeed it is best that clods should be on the surface, where they can be broken down during the considerable period that elapses between the planting and the emergence of the



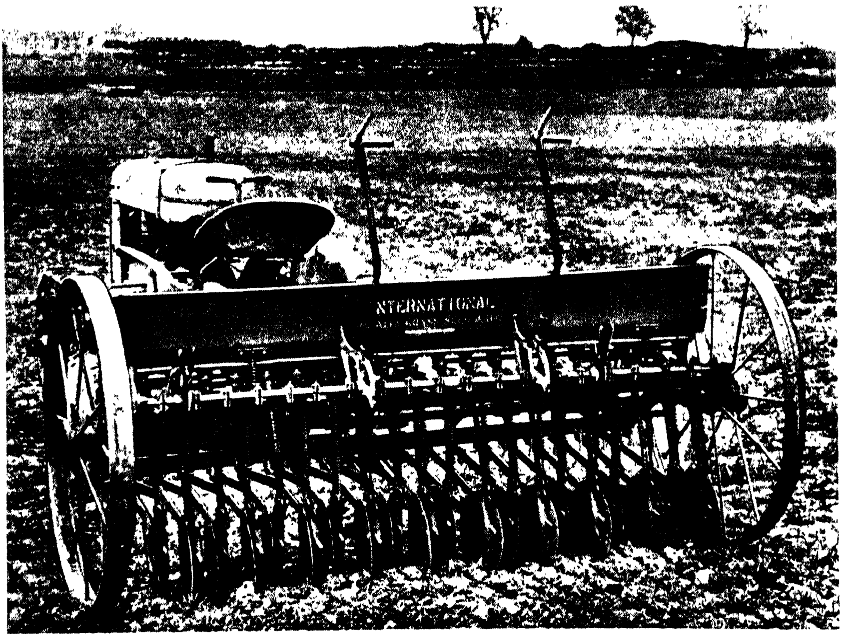
A. Tractor-drawn Sprayer (Barclay, Ross and Hutchison)



B. Agro Sprayer (Ransomes)



A. TRACTOR-MOUNTED BROADCASTER (MACLEAN)



B. "ALFALFA" DRILL (INTERNATIONAL)

crop. On typical potato land that is reasonably free from couch, good results are obtained by ploughing deeply in early winter, and again deeply in March or April. When this has been done a single turn with the cultivator or drag, followed by a harrow, will often be enough to enable the ridging plough or planter to do good work. Alternatively the necessary depth of mould can be obtained, without a second ploughing, by heavy cultivators and drags; but the repeated use of these tends to produce undesirable compaction of the lower layers of the soil. The use of these implements should be avoided altogether if the soil is at all wet below, since in this case a hard and impervious layer will be produced in which only poor root development can take place. Complete removal of twitch is much less important in the case of potatoes than in that of root crops, since the opportunities for weed control after planting are much greater.

WEED SEEDLINGS IN SEED-BEDS

Broadly speaking, conditions that favour the establishment of crop plants will also be suitable for the germination of weed seeds; but there are exceptions. For instance, the kind of tilth that has been described as ideal for autumn wheat is too rough to be ideal for small-seeded species like black-grass and poppies; hence the worst infestations of these weeds are apt to occur when the wheat tilth has been made too fine. Again, oats will establish quite well if there is an inch or so of rather rough material on the surface, whereas charlock requires a fine surface mould. This explains the fact that charlock tends to be most abundant in years when spring frosts have produced a mealy soil condition. By contrast, the condition that is ideal for roots and grass seeds is favourable to the establishment of all annuals.

One method of destroying seedlings is to prepare a tilth and wait until the weed seeds have germinated before drilling the crop and giving the final harrowing. It is unnecessary to wait for the weeds to emerge; indeed the best "kill" may often be obtained before this stage. The ideal time is when a scraping of the soil shows up large numbers of the white thread-like shoots of germinating seeds. Naturally the delay in the sowing of the crop—perhaps for a fortnight after the land has been made ready—may be disadvantageous to the yield and may delay ripening to an undesirable extent.

Certain crops, notably carrots, but also sugar-beet and mangolds, are slower to emerge than most common weeds. If the weeds happen to be abundant the task of weeding by hand labour will be very laborious and the cost may be prohibitive. In such cases there may be an opportunity—necessarily a fleeting one—for " pre-emergence " spraying. As has been explained, DNC and the " hormone " sprays would damage the germinating seeds of the crop and therefore cannot be used for this purpose. Sulphuric acid is, however, not open to this objection, and is to be preferred to copper chloride because it is effective upon a larger range of weed species. A relatively high concentration —say 15 gals. of acid in 100 gals. of water—should be used. The inclusion of some mustard seed with the carrots or beet enables the rows to be seen (since mustard comes up very quickly), and thus allows the spraying to be done without damage by the tractor or sprayer wheels to the crop seedlings.

The next method is based upon the fact that certain crop plants, in the earlier stages of growth, have a stronger roothold than the general run of annual weeds. This statement indeed does not apply in particular cases—*e.g.* the wild oat and corn buttercup are often, by the spring, about as strongly rooted as the autumn-sown cereal in which they occur—but crops of wheat, rye, oats, peas, and beans will usually withstand, without serious damage, a sequence of harrowings that will kill seedling charlock, runch, spurrey, and many other species. Barley is rather more susceptible to damage, so that harrowing, though by no means impracticable, must be done with special discretion.

Spring cultivation—harrowing and rolling—is a normal procedure in the case of winter wheat. It is true that experiments have failed to show many cases of significant benefit to the crop itself. But harrowing should be done whenever there is a considerable infestation of annuals such as speedwell, poppies, and chickweed. Occasionally the land may be so " puffy " (loose) that harrowing would uproot many of the wheat plants, in which case rolling should be done first, and the harrowing postponed for a week or two so as to permit the wheat to improve its roothold.

In the case of spring-sown cereals (as has already been mentioned in connection with undersowing), the harrowing must either be done before sprouting is far advanced or else delayed until the roothold is strong. The earlier stage will generally be too soon to kill many weeds. The land should be inspected after

each successive stroke of the harrows, the operation being stopped as soon as the desired result has been obtained, and in any case before any excessive number of the crop plants has been uprooted. It is worth noting, however, that autumn-sown wheat, in spring, may be over-thick, in which case some degree of thinning will be desirable. The harrows should not follow the direction taken by the drill since in that case a considerable run of plants might be uprooted by a single tine. In the case of beans, breakage of the stems, rather than uprooting, is what must be feared. Hence the harrowing should be done before the stems are tall enough to be broken. Naturally, in some cases the crop will be too far advanced before the soil is dry enough to be harrowed.

The use of weed killers on cereal crops has already been discussed, but one or two general points remain to be mentioned. One is that the data given on page 164, in regard to the effectiveness of sulphuric acid, apply only to weeds that are in the early seedling stage. Some, such as poppies and goose-foot, become much more resistant with age. In general, the best "kill" is obtained with acid when the weed seedlings have no more than two "rough leaves"—*i.e.* two in addition to the cotyledons. On the other hand the "hormone" weed killers cause damage to very young cereal seedlings and spraying with these should be delayed until the plants have begun to tiller; these materials are, however, very effective against charlock, runch, etc., in quite an advanced stage of growth—even up to flowering. In general, DNC can be used over a wider time limit than the hormones.

Undersown crops present a special problem on account of the risk of damage to both clovers and grasses. So far as present experience goes the most effective method of dealing with charlock in an undersown crop is a late application of a weak solution of copper chloride (15 lb. in 100 gals.). This may safely be made when the clovers have reached the four-leaf stage.

Herbage seeds (cocksfoot, timothy, etc.) may be safely sprayed with sulphuric acid (without a wetting agent) as soon as tillering has started. Linseed (but not the fibre sorts of flax) will withstand the hormone sprays after it is about 3 in. high.

ROW-CROP CULTIVATION

"Horse-hoeing husbandry" was first advocated by Jethro Tull before the middle of the eighteenth century—*i.e.* before the

time when roots and potatoes began to be grown as farm crops. It is perhaps worth noting that Tull's system was largely based on a misconception. He believed that the roots of a plant took up minute solid particles of soil, and that these constituted its food. He therefore argued that crops would grow better if the soil were very thoroughly broken down, and pointed out that this could best be achieved by continuing the process of cultivation during the earlier stages of crop growth. In order to extend the period during which cultivation would be practicable, Tull advocated the sowing of crops in widely spaced rows between which a horse, drawing the horse-hoe that he invented, could walk without damage to the plants. Such spacing was found to be practicable in the case of beans, but in that of cereals it involved a considerable sacrifice of yield. Intertillage of cereals, therefore, came to be restricted to the early period of growth—*i.e.* the period during which the plants are not susceptible to serious damage by treading. This limited application of the system to the cereals became normal in parts of the eastern counties, particularly on heavy soils that were unsuited to roots and potatoes. Horse-hoeing of wheat in particular was the normal practice in these areas until the eighties of last century, when the fall in wheat prices tended to make the practice uneconomic. After that time it steadily declined and it is now rare. On the other hand, beans and peas are still, in many cases, grown on the system that Tull advocated.

The principal row-crops of to-day—turnips, swedes, mangolds, cabbage, sugar-beet, potatoes, etc.—have all been introduced or brought into field cultivation since Tull's time. The broadcast cultivation of turnips, involving as it did very laborious hand weeding, was largely abandoned in the early part of the nineteenth century.

It is, of course, obvious that the control of weeds in the earlier stages of development of a crop must be a great advantage to the crop itself. Moreover, in the long run, weed control must be achieved by one means or another, and the use of row-crops does away with the need for the bare fallow and makes for increased over-all production. Whether surface cultivation of land that is carrying a crop has beneficial effects other than the killing of weeds has been a controversial question. The common belief among farmers, and especially among gardeners, is that the maintenance of a surface "mulch" (a blanket of loose soil) checks evaporation and thus tends to maintain the moisture-

content of the layer (say the second 2 in.) upon which the young seedling relies for its water supply. It must indeed be said that few farmers do more intercultivation than is required for weed control, but the same statement cannot be made about gardeners; the latter usually endeavour to maintain a summer mulch whether or not any considerable numbers of weeds appear. "The hoe is better than the watering-can" expresses the widely accepted opinion. The upward "capillary" movement of water is so slow that the amount conserved by hoeing must be negligible. The beneficial effects may, however, be explained as being due to improved soil aeration.

Annual weeds may be killed by cutting them in the region of the hypocotyl—*i.e.* the part of the shoot below the seed leaves. It should, however, be noted that in some species the seed leaves do not emerge above ground. Alternatively they may, in dry weather, be killed by being uprooted; but here it must be remembered that the chance of their taking root again is considerable unless the roots are shaken free from soil. To be fully successful, any sort of hoeing operation should be done when both the air and the surface of the soil are dry. "A wet hoe is better than no hoe," but much less effective than a dry one.

Again, the purpose of hoeing will be defeated if the undercutting of the surface is done at too great a depth. In this case the shallower roots of the weeds will not be greatly disturbed, and will continue to supply the plant with some moisture until new roots can be formed. The optimum depth at which hoe blades should run is usually about 1 in.

As regards stoloniferous weeds the effectiveness of hoeing will depend on the depth at which the stolons lie. Some may be dragged to the surface, and may gradually die from desiccation, but the bulk will usually lie too deep to be reached, in which case all that hoeing accomplishes is to exhaust the food reserves of the plant by cutting off the aerial shoots before these have begun to replenish the underground store. This process of replenishment begins in some species, such as bindweed, within a fortnight of the appearance of leaves, while in others—*e.g.* the field thistle—several weeks elapse before it starts. Naturally the growth of the aerial shoots of deeply rooted perennials, unlike the germination of seeds, is independent of the supply of moisture in the surface layer of the soil, so that the perennials may require attention in spells of dry weather when seedlings are causing no concern.

One of the principles in hoeing is to avoid, as far as possible, damage to the roots of the crop plant. The root system of the young seedling is, of course, small, and its early direction is downwards to secure water, rather than outwards to collect nutrients. In the early stages, therefore, the hoe blades may safely be set to pass very close to the plants, whereas later on a greater interval must be allowed. Again, and especially with shallow-rooting species like turnips, the later hoeings should be very shallow. Another point is that in its early stages the root-hold of the young plant may be disturbed by sideways movement of the soil. This is especially likely to happen if the surface is crusted or capped, an effect that is readily produced by heavy rain falling upon a fine and close tilth. To some extent such " capping " can be prevented by a light harrowing after the surface has been rolled and before germination has begun. Again, tractor-hoes may be fitted with revolving discs to make a clean cut on both sides of the row, and thus to prevent the sideways movement of the soil from extending to the plants. Discs are also helpful in cases where the weeds have grown to some size, and when, without their use, the hoe might throw up-rooted weeds on to the crop.

Horse- and Tractor-hoeing.—The object of using horse- and tractor-drawn implements is to enable the greatest possible amount of ground to be cut by mechanical means and thus to reduce hand work to a minimum. The maximum possibilities are realized when the crop is planted " on the square "—*e.g.* by marking off the land in two directions, preferably at right-angles, and setting the plants at the intersections of the lines. The same pattern may be obtained by " cross-blocking "—*i.e.* by double drilling (the second time at right-angles to the first)—and by horse-hoeing in both directions, leaving a patch of ground some 4 or 5 in. square at each intersection of the drills. Planting on the square works very well with crops that require to be widely spaced—*e.g.* cabbages and brussels sprouts, which can be set respectively 2 and 3 ft. apart each way. But it is scarcely practicable to work tractor-hoes, even when the tractors have special narrow-tyred wheels, between rows that are less than 14 in. apart; and 14 in. square may give a plant population that is too low for maximum yield. The normal practice, therefore, is to drill in one direction, to work the ground between the rows by horse or tractor, and to rely on hand labour for dealing with the narrow strips that remain.

At one time the single-row horse-hoe, drawn by one horse and guided by a man walking behind, was the standard type in many districts. This implied, for a crop sown in 27-in. drills, about three man-hours and three horse-hours per acre. This type was later replaced by a two-horse cultivator with suitable shares so arranged as to deal with three rows. This reduced the labour cost to little more than one man-hour per acre. A further marked reduction can obviously be realized through the tractor, partly because of its greater rate of travel and partly because of the greater width of the implement that can be drawn. It will, however, be obvious that special precautions are necessary if a multiple-row tool is to do satisfactory work. Thus if the ground is uneven it is very difficult to ensure that all the shares will run at the optimum depth, and also, if the drills are not exactly parallel, close work cannot be achieved without the risk of uprooting some crop plants. This difficulty is not surmounted by providing independent steerage for the hoe. For close work in crops that are sown on the flat, the hoe should be either the same width as the drill with which the crop has been sown or alternatively a simple fraction of that width. Similarly a three-row cultivator will do good work in a crop grown on the ridge, for which the ridges have been made by a three-row machine, but it will do bad work if a two-row ridger has been used and has not been skilfully driven.

Work in root crops is generally confined to shallow hoeing, though roots sown on ridges may be slightly ridged-up again as the last operation. The summer cultivation of potatoes is a more complicated affair, which is fully described in the chapter on this crop (see p. 332).

Hand-hoeing.—The flat- or Dutch- or push-hoe is used for inter-row cultivation where the intervals are too narrow to enable the work to be done by horse or tractor tools. The ordinary hoe, which is alternately pushed and drawn, is obviously more suitable for work along the rows, especially if the crop is on ridges. In hoeing, properly so called, and whether or not one of its objects is the singling or " setting out " of the crop plants, it is important to cut the whole of the area that has been left undisturbed by the horse or tractor implements. The point is that, apart from such weeds as are visible, a good many more may not have emerged at the time hoeing is done. It is true that at a late stage in row-crop work it may be desirable to go through the crop in order to chop out occasional thistles and other individual weeds. This,

however, is essentially a different operation and it must always be made clear to the workers concerned which of the two is intended.

Other Hand Operations in Weed Control.—There are still particular occasions, apart from the hand-hoeing of row-crops, when manual labour may be profitably devoted to the destruction of individual weed plants. Thus the farmer should keep watch for the first appearance of specially obnoxious species like the wild onion, hoary pepperwort (*Cardaria draba*), or onion couch, and have these forked out of the ground. Again, workers may usefully be sent through crops of corn to pull docks, the operation being most satisfactorily carried out when the soil is too wet for summer cultivation. Odd plants of charlock or of fat hen in root crops during late summer may be profitably hand-pulled in order to prevent their seeding. In this connection it should be noted that many species, including especially the dock, can ripen a large amount of seed even if pulled at the beginning of flowering ; these should be carried to the end of the field and thrown into heaps to rot. Finally, hedgerows and roadsides may contain species that are capable of spreading on to adjoining fields, and such should be mown before they reach the flowering stage.

CHAPTER VII

SOWING, HARVESTING, AND BARN MACHINERY

THE SOWING OF SEED AND THE SPREADING OF MANURES

SEED may be sown by broadcasting, dibbling, drilling, or ploughing in. The most suitable method for each of the farm plants is considered under the heading of "Crops." Drilling (including space drilling and mechanical dibbling) is the most modern method, and under normal conditions the most economical. Land must, however, be in fairly dry condition before drills can be worked satisfactorily, and in late seasons and on heavy land an earlier seeding may sometimes be possible by broadcasting. A higher seed-rate may be necessary when broadcasting is practised, and horse-hoeing is seldom possible in a crop seeded in this way, but the land is more completely covered by the crop and a greater smothering effect is secured. In drilling, the headlands must usually be sown first; otherwise they become so heavily trampled that regular planting is impossible.

Broadcast Sowers.—Different types of broadcasting machines are available for scattering different kinds of seed. On some hill farms cereals are broadcast by hand from a sowing-sheet or hopper, machines being used for the distribution of grass and small seeds only; elsewhere hand-sowing has been all but abandoned, mechanical distribution being the rule. A small hand-operated device for broadcasting seeds is the "fiddle," which consists of a small hopper for carrying the seed, a horizontal rotating disc, and a bow, the string of which is looped round the disc spindle. As the man walks across the field with the fiddle hanging from his shoulders he moves the bow from side to side, thus causing the disc to spin rapidly and spread the seed as it falls from the hopper. The fiddle is only suitable for small acreages, but large machines built on the same principle, with the disc driven mechanically, are available for broadcasting fertilizer as well as seed. The common type of broadcast machine consists of a wheeled and shafted framework carrying a long seed-hopper

mounted at right-angles to the line of draught. The seed-hopper may be mounted on the front of a tractor. The seed delivery apparatus, which may be in the form of brushes, cups, or pinion wheels, is mounted on a shaft which rotates in the bottom of the hopper and passes the seed out and on to the ground through delivery holes or ports. The ports, which are placed at short intervals across the machine, can be adjusted to various sizes according to the type of seed and the weight that is required per acre. Plate X, *A*, illustrates a tractor-drawn model.

Drills.—The modern corn drill (Plates X, *B*, and XI, *A*) has a large-capacity hopper mounted on a frame carried on two wheels; a seeding mechanism, driven from one or both of the land-wheels, to feed out the seed; coulter tubes to take the seed to ground level; and coulters which cut grooves in the soil to receive the seed. The drill, if horse-drawn, may be fitted with a fore-carriage, which necessitates an extra man for working but enables the drill to be steered accurately. The wheels on the fore-carriage are adjusted so that when one is held in the track made by the appropriate main wheel on the previous bout, the distance between the two rows sown by the outside coulter is uniform and equal to the row width. Drills without a fore-carriage are usually run " wheel to wheel," but many American drills have the land-wheels one row width from the outside coulters, and have to be driven so that the land-wheel runs on the outside row of the previous bout.

There are three main types of seeding mechanism: cup feed, external force feed, and internal force feed. The cup feed (Plate XI, *B*) consists of a series of discs on a long shaft extending the full width of the drill and forming the seed-barrel. A cog-wheel on one end of the shaft is connected through a chain of gears with the land-wheel. Near the periphery of each disc are a number of cups on short arms standing out at right angles from the surface of the disc. The cups may be on one side of the disc only, in which case they feed one coulter, or they may be on both sides to feed two coulters. Each arm may carry a large cup on one side and a small one on the other. The alternative cup is brought into use by reversing the seed-barrel. The seed-barrel is carried in the feed compartment, which is behind and slightly below the seed-box. Shutters in the rear wall of the seed-box allow seed to flow to the cups. As the seed-barrel revolves the cups pick up seed and drop it into the coulter tubes. Seed-rate is adjusted by

fitting different sized cogs to the end of the spindle, thus varying the speed of rotation of the barrel. The cup feed is very adaptable. It will sow any type of seed provided the cups are of appropriate sizes, and it does not damage the seed. It is, however, affected by rough and sloping ground and some seed is always left in the drill after the cups have ceased to pick up. A tilting lever is provided on the seed-box to counteract the effect of sloping ground.

Both the external and the internal force feed mechanisms are placed in the bottom of the seed-box and they can therefore sow all the seed in the box. The external force feed (Plate XII, *B*) is a series of fluted rollers mounted on a square shaft. The seed-rate is determined by the amount of roller exposed to the seed. The internal force feed (Plate XII, *A*) consists of small dished discs on a square shaft. The surface of the disc is corrugated. The discs are usually double-sided, one side having a shallow dish to deal with the small seeds, and the other a deeper dish for larger seeds. The seed-rate is adjusted by varying the speed of rotation of the discs. As the force-feed mechanisms revolve they draw seed from the seed-box and deliver it to the coulter tubes. They are unaffected by sloping or uneven ground, but they cannot deal with as wide a variety of seeds as the cup feed; they tend to crack very large seeds and often cannot be adjusted to sow small quantities of the smaller sorts. The coulter tubes are usually made of flexible steel ribbon or of telescopic steel cylinders. The Suffolk is still a common type of coulter fitted to British drills, but single- and double-disc coulters are becoming more popular. The latter penetrate the soil better than the Suffolk coulter, do not clog with surface trash, and help to improve the tilth of the seed-bed. The coulters are staggered to give the maximum amount of clearance between them. A lever is provided for raising and lowering the coulters and for putting the seeding mechanism in and out of gear. The same lever may also be used to exert pressure on the coulters, through springs or a press bar, where it is necessary to assist penetration. Small weights hung on the coulters have the same effect.

Makers provide directions for setting their machines for different sizes of seed and rates of sowing, but the delivery rate can be checked by putting bags on the coulters, which are kept clear of the ground, and driving the drill for a measured distance. Many drills are fitted with meters which show the acreage that has been covered and so enable the rate of sowing to be checked

from time to time. On some machines the coulters have a certain range of lateral adjustment which allows of the drills being made at any required distances apart, and for drilling roots on the flat some of the coulters may be removed and their delivery ports shut off. For example, a thirteen-coulter drill with 7 in. between coulters can be converted into a five-row root drill with 21-in. rows.

Large drills for tractor haulage sow twenty-four or twenty-eight rows; they are provided with a separate lift for each half of the machine, an arrangement which not only enables the coulters to be lifted for turning but also allows one half to be used alone, so as to avoid excessive overlapping when finishing a field. However, a set of three 7- or 8-ft. drills may be preferred to one large drill for tractor work as the total sowing width is more than that of a single large drill, and the three narrow machines follow uneven ground better than does a single wide one. Drills can also be got with a fertilizing attachment consisting of a second hopper to hold the manure, and a distributing mechanism, usually of the star-wheel type, which feeds the material directly into the grain coulter tubes. Occasionally there may be separate grain and fertilizer coulter tubes. Combine drilling obviously saves an operation and puts the fertilizer just where it is needed (see Fertilizer Placement, p. 111). With wheat and barley a granular manure may be mixed with the seed and thus sown with an ordinary drill, 1 cwt. of fertilizer representing about $1\frac{1}{2}$ bushels in the setting of the machine. Under very dry conditions, however, even moderate dressings of certain fertilizers may be harmful. Most corn drills have their coulters 6 or 7 in. apart, but machines with other settings can be obtained.

A recent development is the attachment of the drill to a tractor's three-point implement suspension in such a way that when the lift is put in the "up" position the coulters are raised and the seeding mechanism is put out of gear, while the main weight of the drill is still carried on its land wheels. The complete outfit is short, very manœuvrable, and has the great advantage, over other tractor drills fitted with automatic lifts, that the coulters can be raised while the outfit is stationary.

The "International" alfalfa drill, with twenty disc coulters at 4-in. spacing and with a miniature internal double-run force feed, is designed for sowing lucerne, but will handle grass-seed mixtures satisfactorily. The John Deere grass-seed drill is similar,

except that it has a miniature external force feed. The narrow spacing of the coulters enables the young grass to cover the ground quickly.

Root Drills.—Although the ordinary corn drill is often used for sowing roots on the flat, most farmers have special root drills. These are built on the same general lines as the cup-feed corn drill, but are much lighter. Some have an arrangement by means of which it is possible to steer the bar carrying the coulters independently of the drill chassis. Another seeding mechanism is the brush feed which pushes the seeds through a round hole in a plate fixed near the bottom of the seed-box. The plate has a series of holes of different sizes, one of which is chosen according to the kind of seed and the required seed-rate. The coulters on root drills are sometimes equipped with light harrow teeth to pull soil over the seed, and with light single-wheel rollers to consolidate the soil. The rollers may rise and fall independently of the coulters or they may be rigidly attached to the latter so as to regulate the depth of sowing. The "slutherum" drill has small, light mould-boards which throw a miniature ridge over the seed. This ridge is harrowed down, just prior to the emergence of the crop, so as to kill weed seedlings.

Some root drills consist of a number of independent self-contained seeder units mounted on a common frame, which is often a tractor tool-bar. The mounting is such that the individual seeders follow uneven ground surfaces. Each unit has a seed-box, a seeding mechanism, and a coulter which is followed by tines, and a single wheel roller for covering in the seed, and it may be preceded by a land wheel. There is no coulter tube: the seed falls straight from the seed-box into the coulter. The seeding mechanism, which is driven by one of the land wheels, may be cup, brush, or agitator feed; on precision drills, developed primarily for sowing processed sugar-beet seed, it is a rotor, on the circumference of which are shallow depressions just large enough to take one seed. The speed of the rotor is adjusted to give the desired spacing of single seeds in the row. Single-row seeder units are used to sow small plots, particularly market garden crops, and they are usually pushed by hand.

Small seed boxes, one to each row and each containing a separate seeding mechanism, may replace the single large seed hopper on the common root drill. All the seeding mechanisms are connected by a shaft driven from one or both of the land

wheels. The American " corn " and " cotton " planters are of this type; their seeding mechanism is a revolving plate, with holes near its periphery, placed in the bottom of the seed-box. As the plate revolves each hole picks up a group of seeds and carries them round to the coulter tube. Separate fertilizer boxes are also provided for each row. The fertilizer is conducted to the ground in its own tube and goes into the same coulter as the seed, but the coulter is so designed that the seed and fertilizer do not become intimately mixed. This type of drill, as well as the lighter

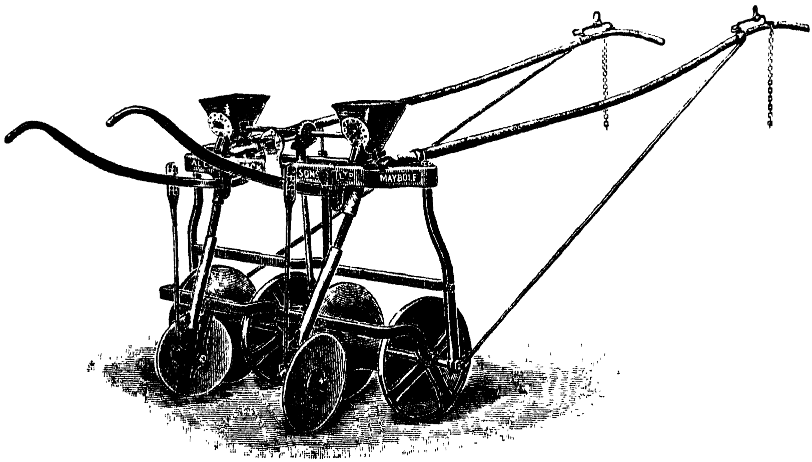


FIG. 13.—Root Drill (Jack)

models of the common root drill, is sometimes attached to the tractor's power-lift, so that it may be lifted clear of the ground for turning on headlands and for transport.

The special type of drill designed for sowing root crop on ridges, and illustrated in Fig. 13, has separate seed-boxes for each row, but here the land wheels are replaced by moulded rollers, which, as well as providing the drive for the seeding mechanisms, keep the implement on top of the ridges and consolidate the ground in front of the coulters. Flat rollers can be obtained for fitting behind the coulters to counteract their loosening effect. Some machines of this type are fitted up so that they can deposit water, liquid manure or artificial fertilizer with the seed.

Manure Distributors.—Machines in great variety are available for the distribution of artificial fertilizers; for large applications these are more economical than hand distribution,

and they are certainly more conducive to the comfort of the operator. Some of the more important distributing mechanisms are: rapidly revolving horizontal discs; slotted reciprocating plates forming the base of the fertilizer hopper; a plain roller rotating in the bottom of the hopper and carrying the fertilizer through a slot; an endless chain dragging scrapers along the floor of the hopper and forcing fertilizer through slots; a slowly moving canvas belt in the bottom of the hopper which carries the fertilizer to a revolving brush outside; a series of slowly rotating "soup plates" below the hopper which take the

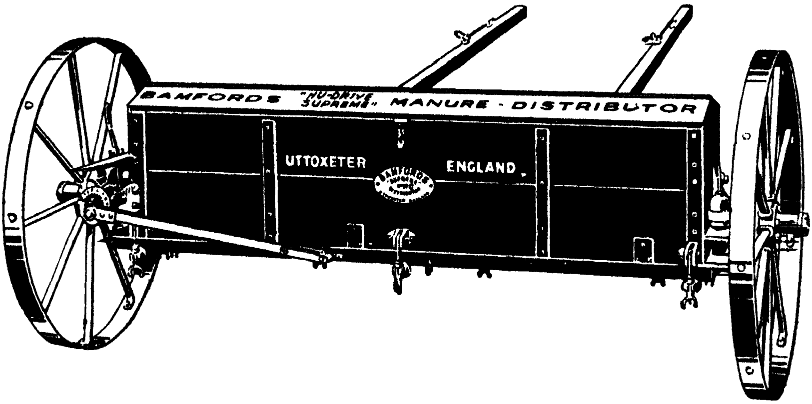


FIG. 14.—Manure Distributor

fertilizer to rapidly rotating flickers; and star wheels rotating in the bottom of the hopper and pushing the fertilizer through slots. One of the mechanisms, illustrated in Plate XIII, *B*, is the star-wheel mechanism used in the fertilizer hoppers of combined grain and fertilizer drills.

To facilitate loading and rapid spreading the broadcasting machine may be fixed behind a cart or trailer drawn by a tractor. A man in the cart, which carries a load of fertilizer, fills up the hopper as the outfit goes along. Another type consists of a hopper that is fixed to, and carried on, the rear of a lorry, the mechanism being driven by gearing from the lorry wheels.

Special fertilizer distributors, some of which are tractor-mounted, are constructed with two or three spouts for depositing fertilizers in the bottoms of potato and turnip ridges. Some standard distributors can be adapted for the same purpose by fitting baffles below the distributing mechanism.

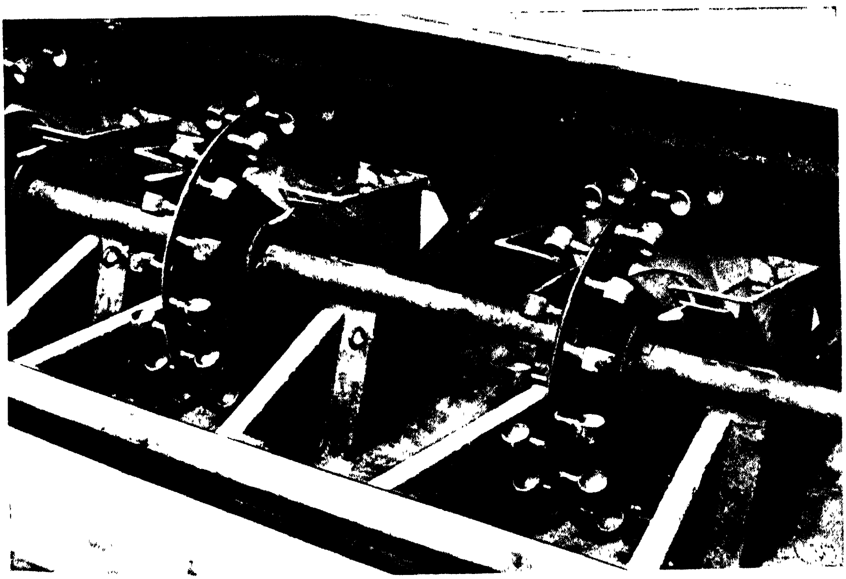
Manure distributors must be very thoroughly cleaned after use, since most fertilizers are somewhat deliquescent and cause rapid corrosion of the metal parts.

Moderate dressings of ground lime and ground limestone may be spread by manure distributors. Special lime-spreading appliances, suitable for contractors and designed to apply the lime at rates up to 2 tons or more per acre, have been introduced in recent years and are now used on an extensive scale (Plate XIV, *A*). Some are built on lorry chassis, so that when working within easy reach of the lime works they can cart the lime and spread it without any additional handling. The lorry body is replaced by a large-capacity hopper, in the bottom of which is a conveyor to carry the lime back to the spreading mechanism on the rear. One type of distributing mechanism consists of three rapidly rotating impellers placed across the machine. The central one spreads the lime beneath the vehicle, and the lateral ones drive the lime outwards beneath a wind shroud. The impellers are driven by direct-coupled electric motors. The width of spread is about 30 ft. Another type of spreading mechanism is a revolving horizontal disc having a width of spread of about 20 ft. Other machines are designed to be drawn by tractor and driven from the tractor power-take-off.

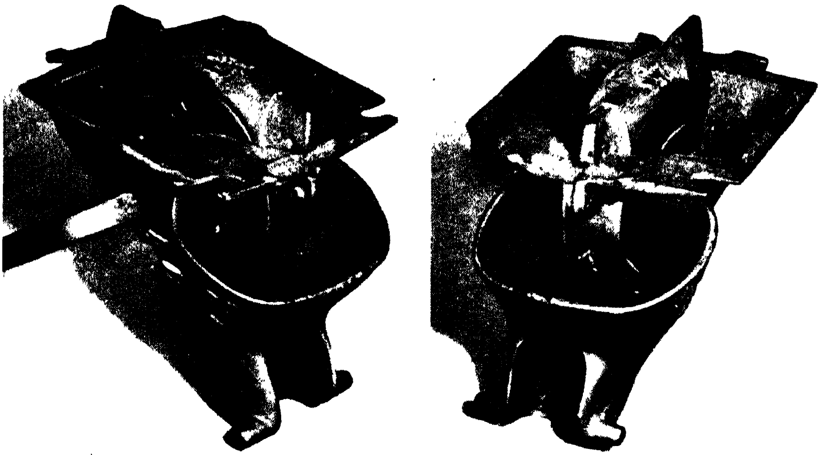
Attachments are available for converting some of the American types of farmyard manure spreaders for lime (Plate XIV, *B*). The "back-axle" type of distributor is made by attaching a disc to the shortened propeller shaft of the back axle of a car or lorry. The back axle is rotated through 90° so that the shaft is upright. As the machine is pulled forward the disc is driven at high speed by the wheels acting through the differential. Lime is allowed to fall on to the disc from a hopper or is shovelled on to it from the towing lorry or tractor-drawn trailer.

Farmyard Manure Spreaders (Plate XV, *A*) are made in the form of low two- or four-wheeled wagons, with false creeping bottoms that carry the load towards the mechanical forks or kickers situated where the tail-board normally is. These machines are entirely mechanical, and the energy by which they empty themselves and scatter the dung is transmitted from the rear wheels through suitable gearing. The larger models require three horses or a tractor for their draught, and the time taken to spread a load (about 1 ton), at the rate of 14 tons per acre, is about five minutes. Another machine differs from the above

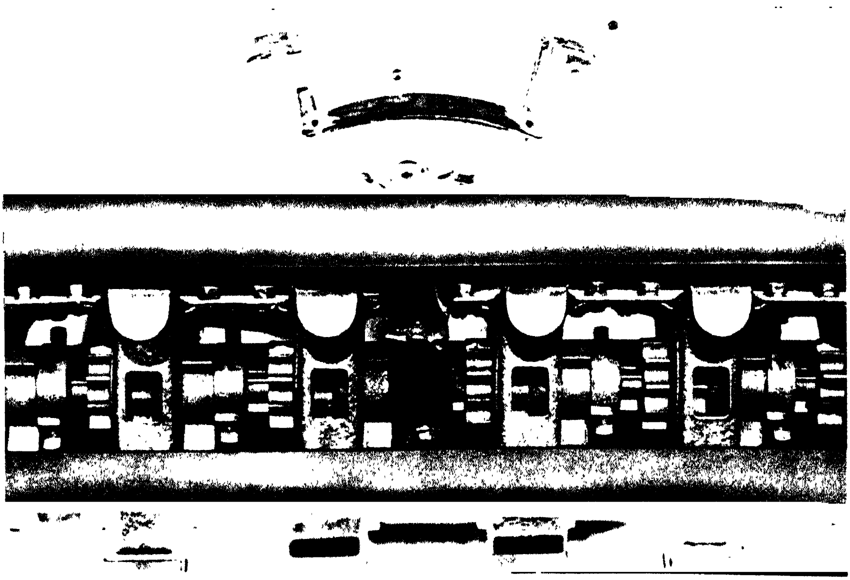
A. TRACTOR DRILLING.



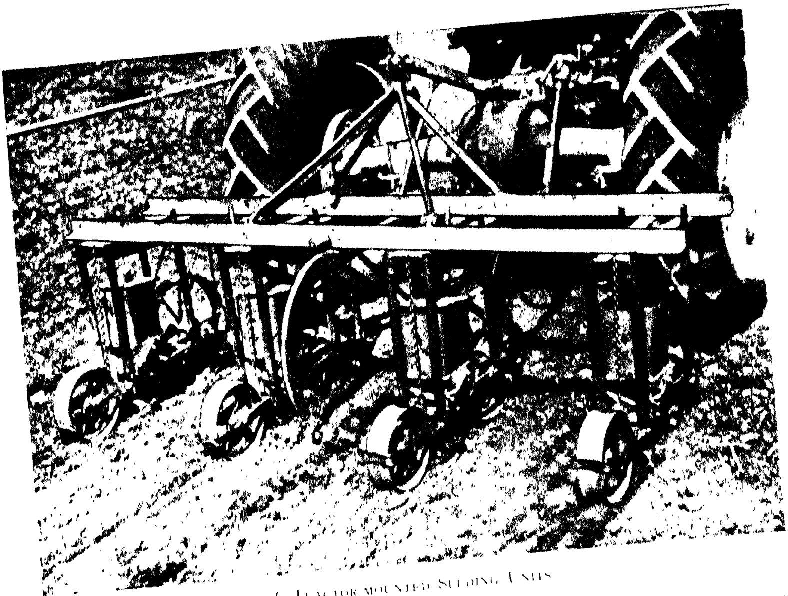
B. DRILL SEEDING MECHANISM. CUP-FEED.



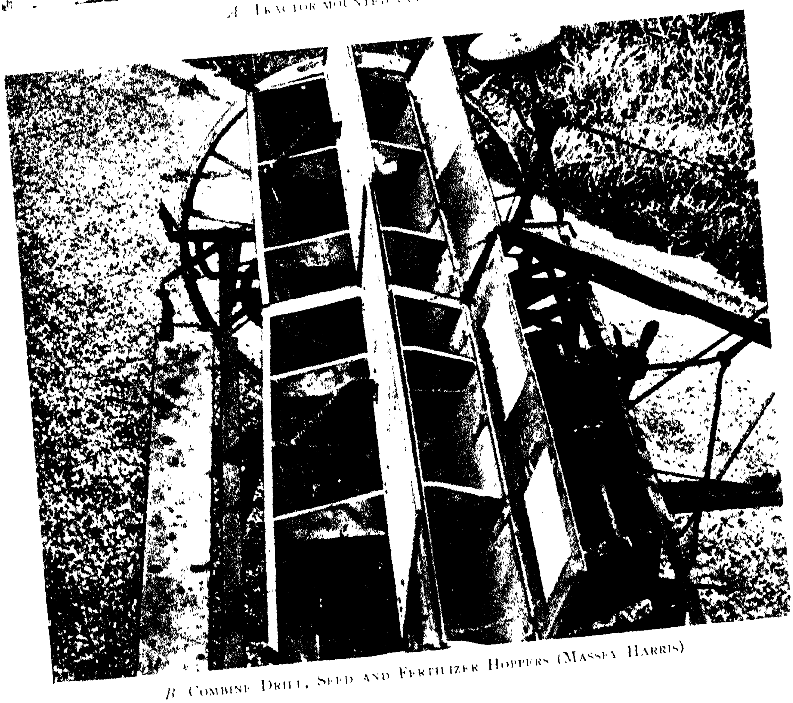
A. Drill Seeding Mechanism Internal Force-feed



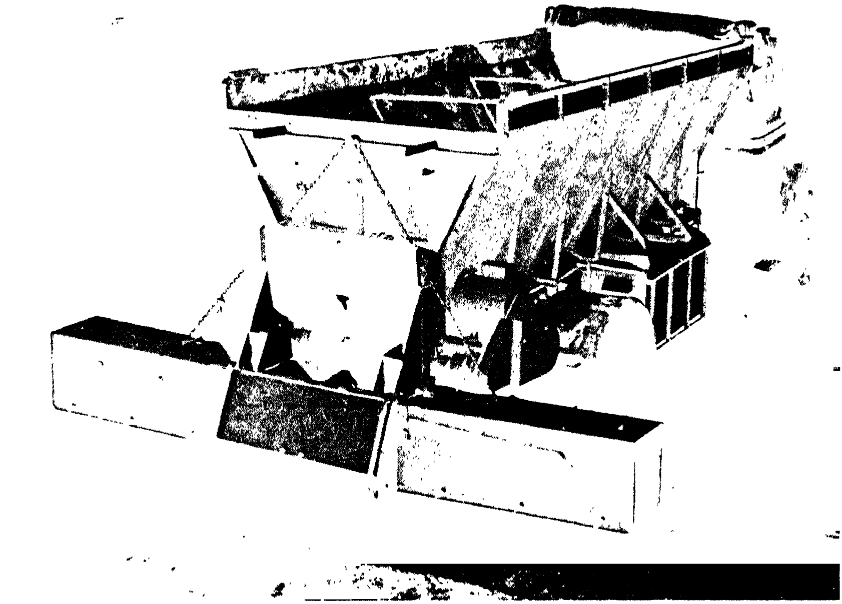
B. Drill Seeding Mechanism External Force-feed



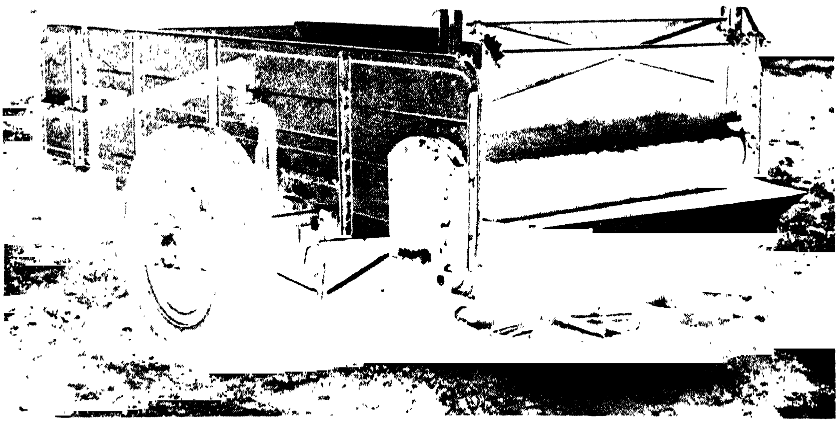
A TRACTOR MOUNTED SEEDING UNITS



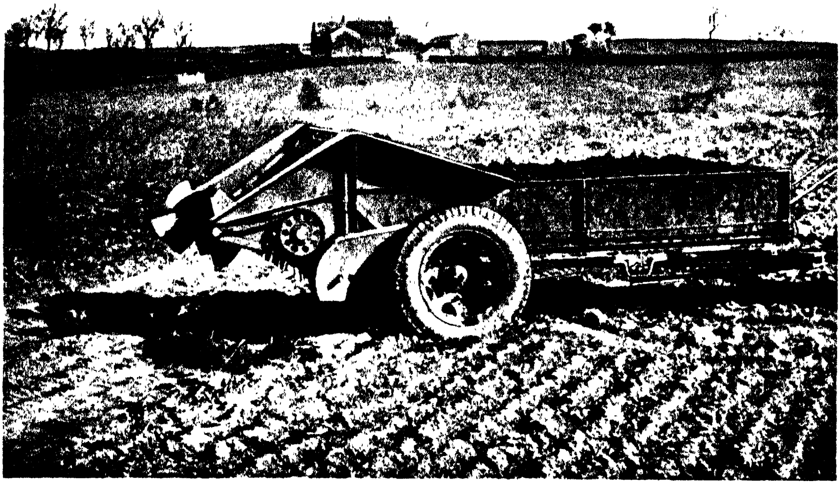
B COMBINE DRILL, SEED AND FERTILIZER HOPPERS (MASSEY HARRIS)



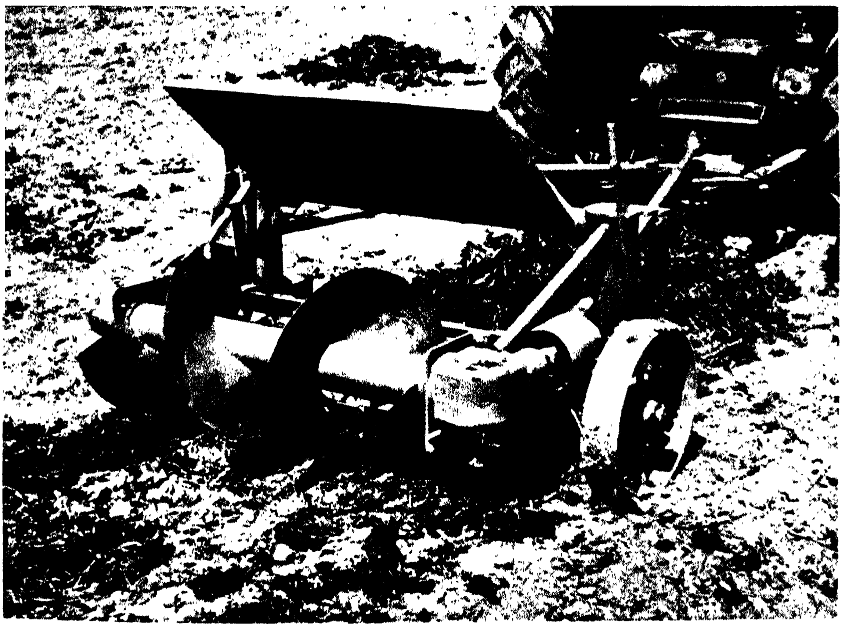
A. Markjohn Lime Spreader



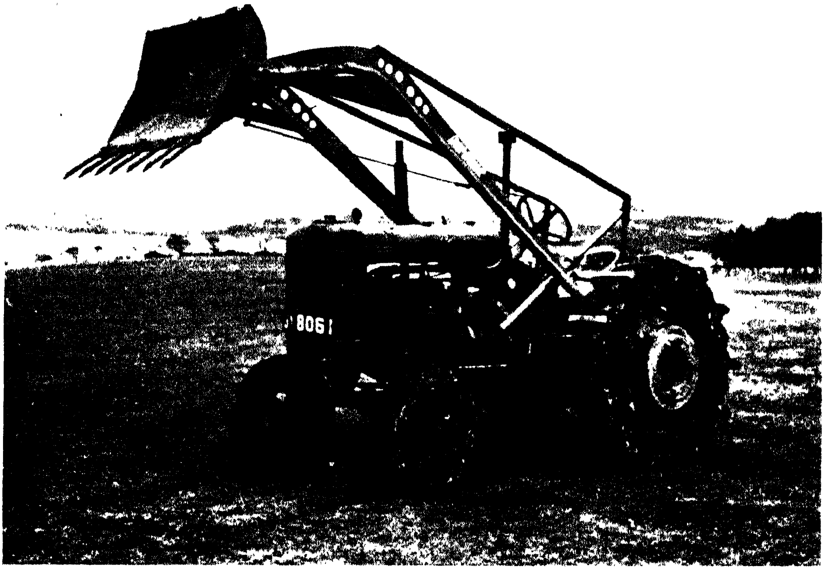
B. Lime Spreader (Atkinson)



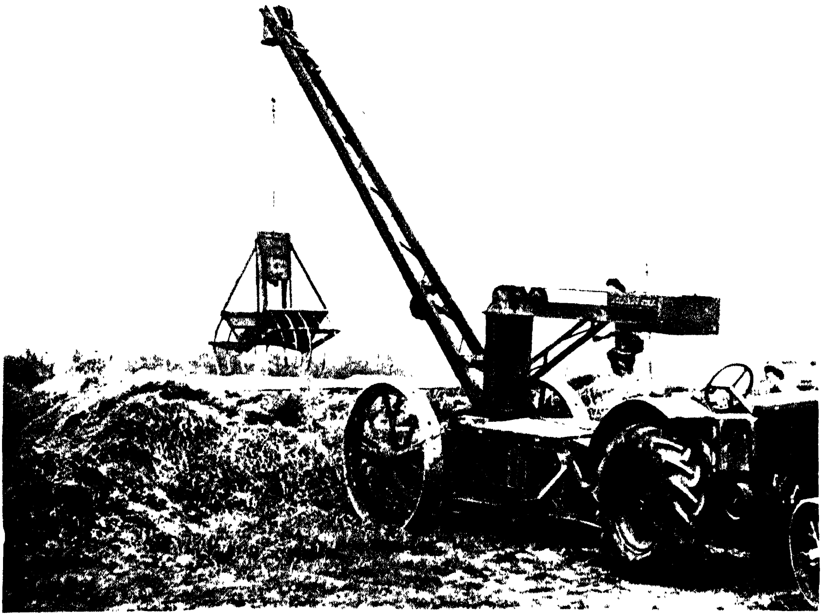
A. Farmyard Manure Spreader (Fairmile)



B. Dung Spreader (Wild-Thwaites)



A. Tractor-mounted Fore-end Loader (Horndraulic)



B. Grab-type Dung Loader (Ransomes and Rapier)

in that its mechanism is driven from the power-take-off of the towing tractor and that delivery is at the front of the body. A spreader may be very handy if it can be kept beside a ramp and filled as dung accumulates, each load being taken away and spread as soon as the spreader is full. This may be possible on certain farms, at least at certain seasons, but the distribution of unfermented dung is often undesirable. Machines may have difficulty in dealing with long dung, but mechanical distribution is very easy if the bedding straw has been chaffed. On a large arable farm three machines would be required to complete a set for economical working, and their cost may prove excessive. Spreading by hand can sometimes be done when no other productive work is available.

The spreader illustrated in Plate XV, *B*, works on small field heaps set out as for hand spreading. It is tractor-drawn and is driven from the tractor power-take-off. As it is drawn over the heaps a high-speed rotor, running at ground level, disintegrates and spreads the dung. The machine can also be used for spreading coarse lime—*e.g.* shell sand or waste lime products, set out in small field heaps.

Liquid manure is usually transported in a tank mounted on a cart frame, and is distributed by allowing the liquid to flow into a perforated tray or a grooved spreader which is placed across the back of the machine.

Dung Loaders.—Obviously a power-driven device for loading farmyard manure on to carts or spreaders would save a great deal of heavy work. It is desirable that the dung should be moved in such a way that it will not be unduly difficult to spread. In fact, much progress has been made in developing machines for this purpose. Several different principles are used; some machines are worked by the farm tractor and others have their own engines. A small two-man outfit consists of a motorized winch and elevator and a fork attached to the wire rope on the winch. The elevator and motor stand at a convenient place for delivering the farmyard manure into a cart or trailer. One man pulls the wire off the winch until he can push the fork into the heap of manure, and the second man controls the clutch on the winch. The loaded fork is pulled to the base of the elevator, on to which it discharges its load. This loader can be used to clean out loose-boxes and other buildings which cannot be entered by a tractor, and with the help of a snatch block can move the manure round corners.

Tractors with front-end loaders, which are raised and lowered hydraulically, are used as dung loaders (Plate XVI, *A*). They require room to manœuvre in yards and are sometimes handicapped by wheel spin on the floors of the yards. Another type of loader (Plate XVI, *B*) takes the form of a crane and grab.

The Mechanical Byre Cleaner is a conveyor belt running in the dung channel. The dung and litter are raked on to the belt, which is then pulled along the gutter by being made to wrap itself round a revolving shaft, and the dung falls off the belt into a waiting vehicle. The empty belt is pulled back into the gutter and remains in this position until further dung has to be removed.

THE CUTTING OF CROPS

Except for very small acreages, or for badly laid cereals, the scythe and reaping hook are now seldom used in the cutting of crops. They have been almost entirely superseded by the mower for cutting hay and forage crops, and by the reaper or binder for harvesting cereals and beans. "Combines" or harvester-threshers are now very common. Special methods have to be adopted for certain crops. If peas are cut with a mower it is necessary to move each swath as it is cut to one side so as to make a clear path for the mower on the next bout. The peas may be moved over by hand, or a side-delivery rake may be used. A special pea cutter is also available (see p. 203). Flax, because of its long and valuable fibre, is usually pulled by hand or by machine.

If neatness is aimed at and labour is available, the scythe may be used to open "roads" round the fields so that the horses may not trample nor the implements crush down any of the crop, but this is neither absolutely necessary nor especially advantageous as a preliminary to mowing. It is, of course, quite unnecessary in the case of a self-propelled combine, because in this case the cutter-bar is in front.

The use of a high-speed mower produces the most thorough cutting and leaves the shortest stubble. Such a machine can usually deal with a "lodged" crop. The most effective implement for dealing with laid and tangled crops is, however, a combine harvester equipped with a "pick-up" reel. A good upstanding crop can be cut round and round with any harvester, but when strong winds have given the corn a pronounced lean in one direction, cutting two ways, or even one way only, against

the bend, may be necessary. Every farmer uses his own discretion in the choice of implements, and, by reason of its economy in time and money, uses the binder or combine for cereals whenever feasible.

The Mower.—The modern two-horse mower (Fig. 15) consists of a framework mounted on two wheels, suitable gearing to transmit the power from the wheels to the cutting apparatus, and a cutter-bar containing a reciprocating knife. The shaft is mounted on the frame, and when the driver occupies the seat the

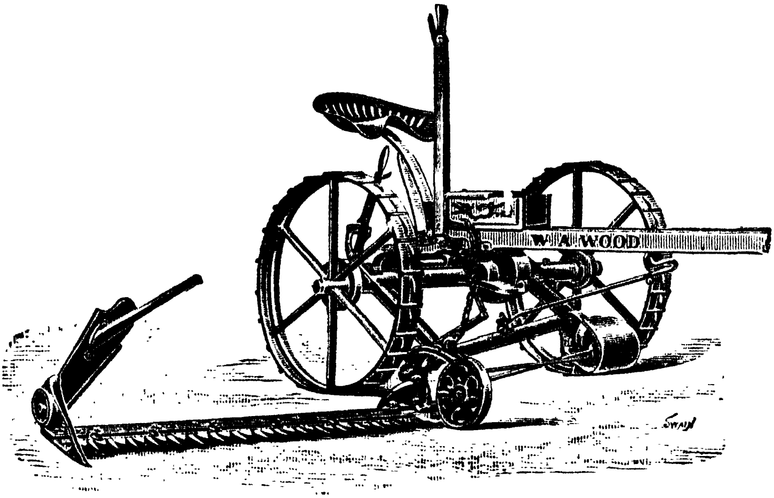


FIG. 15.—Horse-drawn Mower

machine is well balanced. The gearing, which may be taken from one or both wheels, is high speed, and the bearings are ball, roller, or plain, according to their positions. A dog clutch is provided to put the mechanism in motion, and is disengaged for convenience in travelling. The cutter-bar may be either on the nearside or the offside of the machine; its usual width in the two-horse model is 4½ or 5 ft.

The cutting apparatus consists of a long bar furnished with projecting fingers, the function of which is to hold the herbage while it is being cut by the knife, and to prevent the knife from entering the ground and being damaged. The fingers are slotted horizontally to allow of the insertion of the knife and its movement to and fro. A " twin-finger " cutter-bar will enable a machine to deal successfully with short grass. The knife consists of

triangular steel knife-sections riveted to a steel bar. The rivets are easily punched out, and new sections can be inserted when the old ones are worn or damaged. The knife is retained in position by steel clips and moves over hardened steel wearing-plates, which reduce friction in a piece of mechanism that is difficult to lubricate. At the end of the cutter bar is an adjustable swath-board which rolls the cut herbage to one side in the form of a swath, and leaves a clear track behind the machine. A very small wheel is placed behind the swath-board to take the weight of the cutter. A tilting lever attached to the bar allows of very close cutting when the ground is smooth, and of elevation of the fingers when stones or unevenness of surface renders close cutting undesirable. The whole of the bar is hinged and can be moved into an upright position for travelling. Providing a small engine to drive the mechanism of a two-horse mower enables one horse to pull the machine.

A tractor can be used to haul an ordinary mower fitted with a stub pole instead of a long horse pole, but trailer mowers are specially made of a size and strength suitable for tractor work. Modern tractor trailer mowers have their control levers pointing forward so that they are within easy reach of the tractor driver. The mechanism of the mower may be driven from the power-take-off of the tractor. The great advantage of this system is that, as the knife does not depend on the traction of the ground wheels for its operation, a 6- or 7-ft. cut can be made. With the tractor going much faster than horses the rate of cutting is very high. A safety clutch is incorporated in the power shaft so that in the event of a stone or other foreign body fouling the cutter-bar the clutch slips and no damage is done. Sometimes a trailer mower is hitched so as to cut behind the tractor mower, and the two cutters overtake an enormous acreage in the day. Mowers mounted on the tractor, either on the rear or between the front and rear wheels, and driven from the power-take-off are now available (Plate XVII, *A*). The rear-attached model may be wheelless or may have trailing castor wheels. The cutter-bar of mounted mowers usually has a " break-back " action. This means that if the cutter-bar hits an obstruction it swings back and at the same time disconnects the drive from the power-take-off to the knife, thereby reducing the risk of damage. Reversing the tractor is normally sufficient to bring the cutter-bar back into the working position. A tractor-mounted mower in which the cutting

mechanism consists of three side-by-side rapidly rotating horizontal rectangular plates, with renewable knife sections at the corners, has been developed particularly for "topping" pastures, cutting weeds, and mowing grass that it is not necessary to collect. The plates are driven by V-belts. This mower has now been built into a forage harvester.

A windrower can be attached to the cutter-bar of a mower to roll the swath into a compact windrow for easy loading and to leave a clear space for the tractor or horses and the machine on the next round. The windrower consists of a number of spring steel slats trailing behind the cutter-bar. The length of the slats increases with their distance from the swath-board and their free ends are in the form of a spiral. In the swinging windrower some of the longer slats are pivoted to reduce "drag" when turning.

An important matter in the maintenance of mowers is to ensure that the cutter-bar is kept at right angles to the line of draught. Any backward lag of the cutter-bar automatically throws the knife out of adjustment to the cutter-bar points, and thus makes for very bad work.

The Reaper.—The reaper is designed on the same principles as the mower, but it is adapted for cutting taller crops, and is usually complicated by the addition of a self-delivery apparatus. The introduction of the binder has rendered it obsolete, but a few are still in use, especially for harvesting such crops as must be left loose while they dry.

The simplest reaper has a short platform behind the cutter-bar on which the corn is allowed to gather as it is cut, and from which, as soon as there is enough to form a sheaf, it is dropped by depressing the platform through the agency of a foot-lever.

Some reapers, however, are of the side-delivery type, and are provided with large platforms and revolving rakes and gatherers. As the machine advances, the gatherers, which take the place of the reel on a binder, draw the corn towards the knife and cause it to fall back on the platform, while the rakes sweep the material backwards and to one side so that enough corn is delivered on the ground to form a sheaf, and a horse-walk is cleared for the next round. The sheaves have, of course, to be bound by hand.

Apart from the self-delivery apparatus, an important difference between a reaper and a mower is the construction of the divider at the end of the cutter-bar. As corn grows considerably higher than grass the reaper divider is much bigger, and is followed by a large

wheel to carry the weight of the platform; it is very similar to the outside divider on a binder.

The Binder.—The modern reaper and binder (Fig. 16) is the outcome of many years of patient investigation and experiment, and no single man can claim the honour of being its originator.

The frame of the machine is made almost entirely of steel and is well braced, so that it is both light and strong. The main driving wheel, which is carried in the frame, has to be made very strong, and must be supplied with roller-bearings because it carries most of the weight and, except where the mechanism is

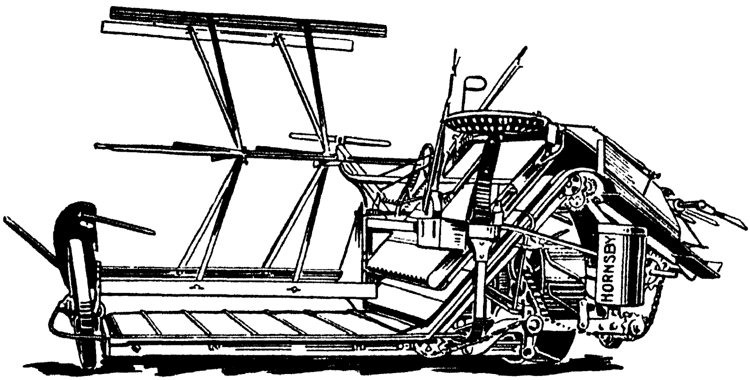


FIG. 16.—Combination Binder (Hornsby)

power driven, is subjected to severe strains. When the machine is started up the power is taken from the driving wheel by a strong chain to a roller-bearing crank, and thence, through a dog clutch, by means of gearing and chains, to the various revolving and oscillating parts of the mechanism.

A steel platform strengthened by crossbars is riveted to the frame, and is supported at its free end by means of a grain wheel. The cutter-bar, which is commonly 5 or 6 ft. wide in horse-drawn models, is situated in front of the platform, its structure and action being similar to those of the mower. In order to prevent the grain wheel overriding a portion of the corn, a wedge-shaped divider is fixed in front of the wheel at the end of the cutter; this not only prevents the standing crop from being damaged but also tends to raise fallen shoots so that they are cut more readily. Special dividers are sometimes used for laid crops. These may be large and torpedo-shaped, projecting well ahead of

the cutter-bar; or they may be ordinary dividers through which a vertical cutter-bar, with a reciprocating knife driven from the standard knife, projects. Another divider is placed at the elevator end of the cutter, but it only comes into action when the machine is " filled " to the utmost. A tilting lever is provided to regulate the height of the cutter-bar. Sometimes " grain lifters " are clamped to the front of the cutter-bar to facilitate the cutting of a lying crop.

The reel, which is caused to rotate by means of gearing, is adjustable by hand-levers, both vertically and horizontally, and can therefore be placed in whatever position is best suited to the length of the crop and the direction in which it may be leaning. Its action is to bend the straw slightly towards the knife so that it may fall naturally on the platform as soon as it is cut. Special reels are available for dealing with laid crops, but they are not yet in common use in this country. They are a great improvement on the standard reel.

As soon as the corn falls on the platform it is received by the bottom canvas and is carried towards the two elevating canvases, which raise the material to the deck of the machine. The canvases are all adjustable, and should be kept just tight enough to prevent slipping on the driving pulleys. Special looseners are usually fitted, which enable the canvases to be slackened in a few seconds when the machine is being left overnight. The leather straps and buckles normally used for fastening canvases are sometimes replaced by a self-adjusting elastic lace which is threaded, criss-cross fashion, through leather loops on the ends of the canvas. This fastening helps to prevent tearing of the canvases when crops are damp. Rubberized canvases, since they are unaffected by moisture, are superior to those that have been generally used.

As soon as the corn reaches the deck it is acted upon by the packers and butters, which jointly compact the material into a sheaf and carry it to the knotter. The sheaf is compacted against a vertical lever which, when a sufficient weight of material has gathered, gives way and engages the binding gear. A curved and threaded needle-arm carries the twine round the sheaf and leaves it in the grasp of the knotter, which ties and cuts the twine; the sheaf is then kicked off the deck by a set of three levers.

The principal adjustments which may be carried out on the deck are those which regulate the size of the sheaf and the position of the band. To regulate the distance of the band from the butt

of the sheaf, a lever is employed which alters the position of the whole of the deck, together with the knotting mechanism, relatively to the elevating canvases and the butter, and it is thus possible to tie every sheaf in the centre, no matter what the length of the straw may be. To regulate the size of the sheaf, the compression and trip levers have a range of adjustment, and the tightness of the twine can be controlled by varying the compression of the spring actuating the trip lever.

The difficulty of moving a binder through narrow field gates or along roads is overcome by providing it with removable wheels for travelling purposes. These wheels are fixed on the front and rear of the frame, the driving and grain wheels are elevated out of the way, the draw-bar is shifted into a position at the extremity of the platform, and the machine is ready for transportation.

All the gearing of the binder is driven from the large wheel of the machine, and the outfit must be kept going at a fair pace if good cutting is to be secured. Any clogging of the knife or other working part acts as a brake on the driving wheel and may cause slip if the ground is soft. Slip stops the cutting and the knife instantly chokes. These difficulties are eliminated when the binding mechanism has a drive that is independent of the traction of the big wheel. A small motor may be fitted to the binder to serve this purpose.

Tractor binders are generally more strongly constructed to withstand heavier work at higher speeds. They may be of the trailer type, with a 6- or 7-ft. cutter-bar, or of the power type, with a 7- or 8-ft. or even wider cut. In the latter case the mechanism is driven from the power-take-off, and the wheels, which only take the weight, may be rubber tyred. They have a safety clutch which slips if the cutter should jam. Power binders have the advantage of speedy cutting and of being able to work on wet or hilly land and in heavy or laid crops where trailer binders would fail. There is now a semi-mounted, power-take-off-driven tractor binder. It does not have a bull wheel and the platform wheel is replaced by a skid. The front of the binder is attached to the tractor's three-point implement suspension and at the rear there are two castor wheels. The control levers point forward so that they can be operated from the tractor seat. This is a one-man outfit and even on sloping ground is very manœuvrable and easily controlled, because the tractor and binder behave as a single implement.

Care of Mowers and Reapers.—For long life and satisfactory working it is of the utmost importance that careful attention should be paid to the lubrication of the moving parts. Most makes have grease-cups, or nipples for grease-gun lubrication, fitted to all the important bearings, but there are also minor bearings that require regular and frequent oiling in order to avoid excessive draught and rapid wear of the parts.

Knives of the ordinary type should be sharpened at least twice a day when the machines are in use, and more frequently on stony land. Spares should be kept so that sharp knives can be fitted as required. Hardened steel knives, which cut a big acreage without need of sharpening, are sometimes used, but they cannot be sharpened with a file and they are easily broken by stones.

Canvases should be slackened off after each day's work, and the machine covered over to protect the parts from rain and dew.

When the season's work is over the machines should be thoroughly cleaned, overhauled, and worn parts renewed; greasy oil-holes should be washed out with paraffin, and all bearings should be left oiled. Parts that are liable to rust may be painted over with a mixture of paraffin and thick oil; the paraffin carries the oil into all the interstices of the mechanism, and when it evaporates leaves the parts coated with a thin protective film. The canvases should be removed and if necessary sent to the saddler to have all rents repaired, broken slats renewed, etc., and afterwards stored in a dry place.

With regard to the problem which presents itself to the farmer as to which make of machine he should buy, there is, in fact, little to choose between modern equipment turned out by reputable makers. A good plan is to purchase from a local agent who carries a full stock of spare parts. The availability of spare parts is of the utmost importance in the case of a breakdown, as delay may bring the harvesting operations to a standstill. Where several machines are bought they should be of the same make so that their parts are interchangeable, and the farmer can afford to keep a few useful spares himself.

Green Crop Harvesters.—Green crop harvesters are used on grass, "seeds," and silage mixtures. The crops may be cut by a mower and then picked up by a buck-rake or a green-crop loader. The buck-rake is similar to a hay sweep, but generally has more closely spaced and shorter tines. It is attached to the rear of a lorry or car chassis or to a tractor with a power lift,

or again it may be a special fitting for a tractor fore-end loader. Green-crop loaders are often very similar to hay loaders: in fact, there are dual-purpose machines suitable for both jobs. On some machines, *e.g.* the Blanch-Snook and Hosier, the elevating mechanism may also pick up the swath, but others have a tined pick-up cylinder which lifts the swath off the ground and delivers it to the elevating mechanism. The standard binder, preferably power-driven, is suitable for cutting silage mixtures, the sheaves of green material being easier to handle than a swath. Loading of green sheaves is heavy manual work, but it can be done by some green crop loaders. A machine similar to a binder, except that it has no deck or knotter mechanism but has the elevating canvases extended to a height suitable for delivering into a trailer, is used for cutting and loading lucerne. It will also deal with other similar crops. Another cutter loader is the Wilder "Cutlift." It has a twin-finger cutter-bar with an elevator which delivers into a trailer drawn behind. It is often used for cutting and loading short grass for drying and can be used for other crops.

Forage harvesters not only cut the crops but feed them through a chopping or lacerating device before loading them into trailers. The chopping is done by a flywheel cutter (like a chaff cutter), or by a cylindrical cutter like the barrel of a lawn-mower. There are two types of lacerating device. In one a long cylinder, carrying radial knife-like projections and revolving at high speed, works in conjunction with a stationary "concave" with similar projections. In the other a fan-like rotor beats the green material against a toothed ring which partly surrounds it. The treated material is then either blown into a trailer by fan blades mounted on the flywheel (see Plate XVIII, *A*) or, in the case of the lacerating machines, by the wind set up by the fast-moving cylinder and rotor, or it is elevated by canvases. On some forage harvesters the cutter-bar can be removed and a pick-up cylinder or a row-crop attachment fitted. The pick-up lifts swaths of green material cut by a mower. The row-crop attachment was designed for harvesting maize, but it has been used successfully to harvest both thinned and unthinned marrow-stem kale. Some harvesters with a cutter-bar will handle broadcast kale. Forage harvesters, especially those with a blower, should be pulled and driven by a tractor having a reserve of power, because if the speed of the engine is pulled down by a heavy crop there is a risk of blockages either in the chopper or in the pipe leading from the blower.

Pea Cutters.—The Leverton pea cutter is a tractor-mounted tool consisting of large torpedo-shaped dividers placed in front of the tractor wheels to part the drill rows and make paths for the wheels, and three large V-shaped cutting blades mounted on a rear tool-bar. The blades cut through the pea stems just below ground level and leave the cut crop standing almost in the growing position. The crop is collected by hand or by a pick-up loader. The " windrower " or " swather " used for harvesting corn can also be used for peas.

Flax Pullers.—On the Boby machine the flax is gripped between a flat rubber belt and a large-diameter revolving drum, and is thus uprooted. There are two pullers, one set just behind the other, and rotating in opposite directions. As the drums revolve they grip and pull the flax and carry it upwards. The belts, as they leave the drums at the top, release the flax, which is then carried to a tying mechanism like that of a binder. The machine is drawn and driven by a tractor. Two operators are required—viz. the tractor driver and a man on the machine to see that tidy sheaves are produced and that all the flax is pulled.

THRESHING

Threshing is the process of removing grain from its straw and chaff, freeing it from impurities, and fitting it for the market. Machines designed for threshing vary greatly in size and capacity for work. As a rule, the output of a machine is proportional to the size of its drum, which may be from 2 ft. to 5 ft. 6 in. wide.

The ordinary English portable thresher has a 4 ft. 6 in. drum, 22 in. in diameter, which revolves at a speed of about 1000 revolutions per minute, and is capable of threshing a maximum of 36 cwt. of wheat or oats or 40 cwt. of barley per hour. Such a machine has to be driven by an engine capable of developing about 20 brake horse-power. While British threshers differ in certain details, they are all constructed on the same general plan. Fig. 17A illustrates a section of a Foster thresher, and Fig. 17B shows a transverse section of a Ransomes model.

The all-steel American thresher is so designed that it can be operated with fewer men than the British thresher. It is invariably fitted with a self-feeder, comprising band cutters and feeding elevators which spread the cut sheaves so that the straw is fed evenly over the full width of the drum. The drum and concave

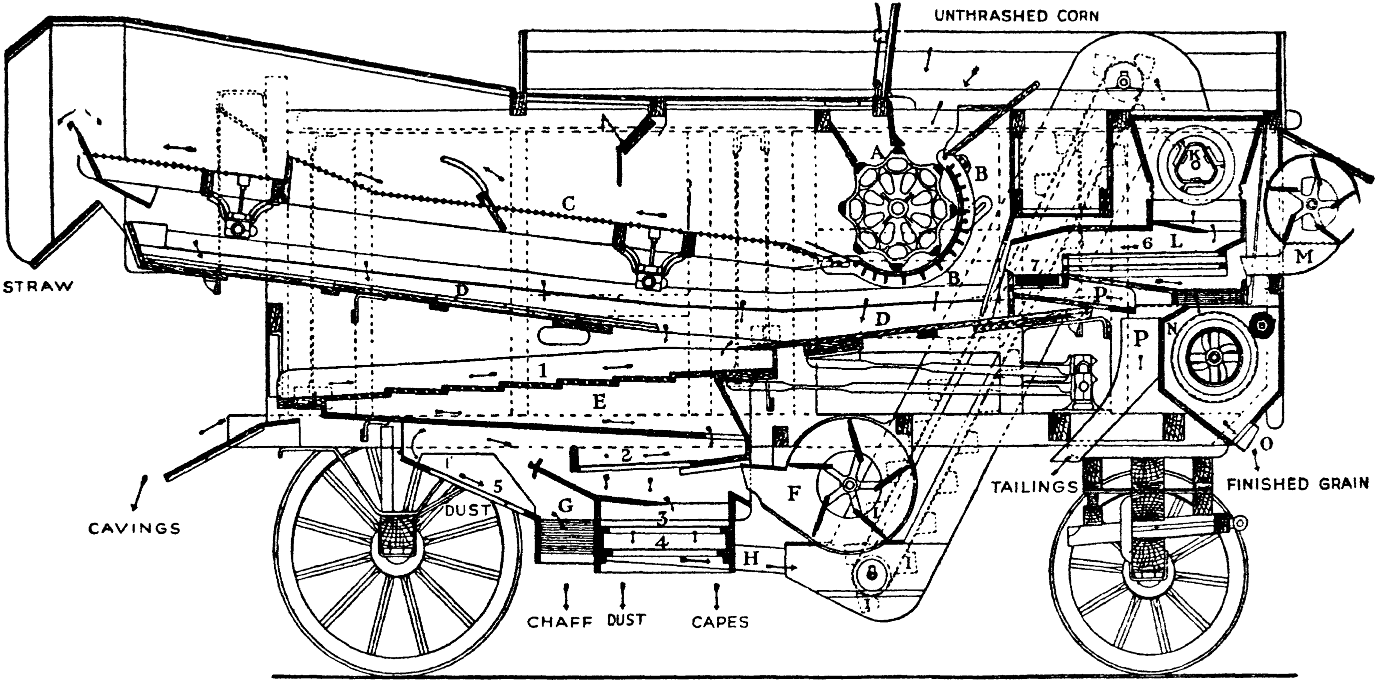


FIG. 17A.—Section of the Foster Thresher

A Drum
B Concave
C Straw shakers
D Top shoe
E Bottom shoe
F First dresser fan
G Chaff spout
H Corn spout
I Elevator cups
K Awner and smutter
L Second dresser
M Second dresser fan
N Rotary separating screen
O Corn outlets
P Tailings spout

RIDDDES

1. Cavings riddle
2. Wind riddle
3. Capes riddle
4. Seeds riddle
5. Chaff sieve
6. Second dresser riddles
7. Tailings riddle

are of the peg type, rows of pegs on the drum alternating with similar rows on the concave. The drum is often used at much higher speeds than the British beater-bar type. Because of its

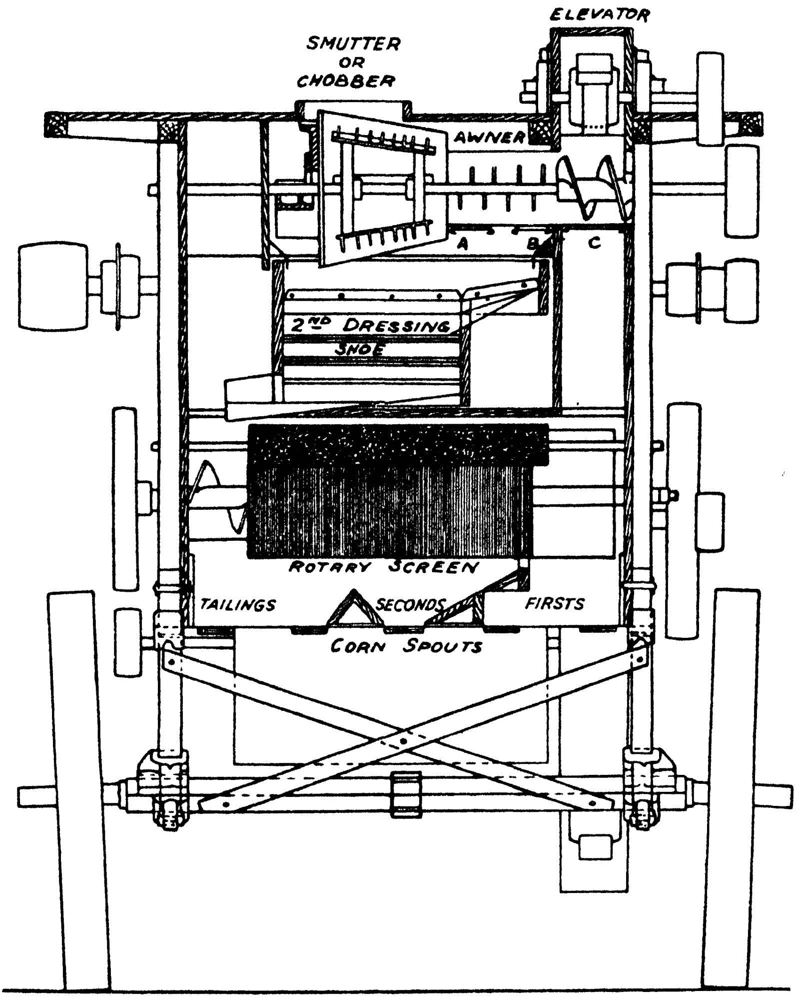


FIG. 17B.—Transverse Section of Ransomes Thresher

construction and the speed at which it is driven the peg drum breaks the straw much more than the British drum. Straw shakers, sieves, and wind are used to effect the separation of grain from straw and chaff. Only one dressing shoe, corresponding to the

first dressing shoe on the British thresher, is employed. The incompletely threshed heads from this shoe are returned to the drum, the light bits of straw and chaff are blown into the stacker along with the bulk of the straw as it comes off the shakers, and the cleaned grain falls into an auger conveyor which takes it to one side of the machine. The grain is then elevated to either a weighing-off apparatus or chutes which deliver it in bulk into grain wagons. The straw and chaff are dealt with by the straw stacker. The stacker may be a simple elevator or a pneumatic conveyor capable of blowing the straw into a heap well clear of the thresher or into buildings convenient for feeding it to stock.

The Operation of Threshing.—The corn is fed into the top of the machine by hand after the sheaf bands have been cut, or is placed on a mechanical feeder. The self-feeder (not illustrated) is usually constructed in the form of an endless travelling canvas carrier, which is fitted with a device for shaking out the sheaves by tedding and oscillation, and may or may not be fitted with a band cutter. The object of self-feeders is, of course, to economize on labour; and most makers fit them as extras. When the corn enters the machine it falls between the revolving drum and the concave, and the grain is knocked out of the ears. The mixed material passes on to the shakers, where the grain and chaff are thoroughly shaken out, while the straw is passed out at the end of the machine; it may be allowed to fall on the ground, or it may be received by an elevator and transported to the stack; or a trusser may be fitted which automatically ties the straw into bunches with either single or double strings; or a supplementary baler may be used to compress it into wire-bound bales.

Everything that descends through the concave and shakers falls on the collecting-board or top shoe, which by its oscillation carries the material back to the middle of the machine and allows it to fall on the cavings [1] riddle. The oscillation of this riddle, assisted in some makes by blast, carries the cavings forward and delivers them on the ground below the straw-board; but the chaff, grain, etc., fall through to the bottom shoe or collecting-board, and are again carried to the middle of the machine where they fall through an opening on to the wind riddle, which receives a blast of air from the large blower. This blast removes the chaff from the grain

[1] The term "cavings" is applied to the short strawy material that passes through the shakers. It contains leaves, some empty ears, and broken pieces of stem.

and weed seeds, and either delivers it on the ground or passes it into bags through a special bagging apparatus.

The winnowed grain passes into the first dressing apparatus, which is designed to remove pieces of ear, stones, weed seeds, etc., and then down an oscillating spout into the endless belt-and-cup grain elevator. The grain may be delivered from the elevator :—

1. Through the awner and smutter, which removes beards and polishes the grain, into the second set of dressing riddles, where it is subjected to a blast of air from the small blower and freed from dust, awns, etc., and then into the rotary screen, which removes weed and thin seeds, sorts the grain into two sizes and delivers the material to the corn spouts.

2. As in 1, but without going through the smutter.

3. To the second dressing apparatus without passing through either the awner or smutter, and thence through the rotary screen into bags.

4. Directly into bags.

The Practice of Threshing.—The thresher is provided with two spirit-levels, and, if the work is to be satisfactory, must be placed absolutely level before operations commence. The transmission of power from the engine is by belt, and the driving and driven pulleys must be perfectly aligned if the belt is to be prevented from jumping off. The belt must not be too tight or it will throw undue strain on the bearings, which may heat. All bearings must be kept thoroughly oiled and cleaned. The machine should be gone over after every day's work, and all nuts should be kept properly tight. Should a knock or grinding noise develop during threshing the machine must be stopped at once and the fault remedied, otherwise a serious breakdown may occur. Feeding must be regularly and carefully performed, and any damp material should be fed very slowly: a choked drum resulting from overfeeding throws an enormous strain upon the mechanism and may cause a breakage.

The sample of grain must be examined from time to time to ascertain its condition; the straw should be examined for thoroughness of threshing, and the chaff for the presence of grain. Whenever imperfect work is being done the cause should be ascertained and the fault remedied immediately.

When certain parts of the machine are not in use, for example the awner or the rotary screen, their driving-belts should be removed to reduce wear and save engine power.

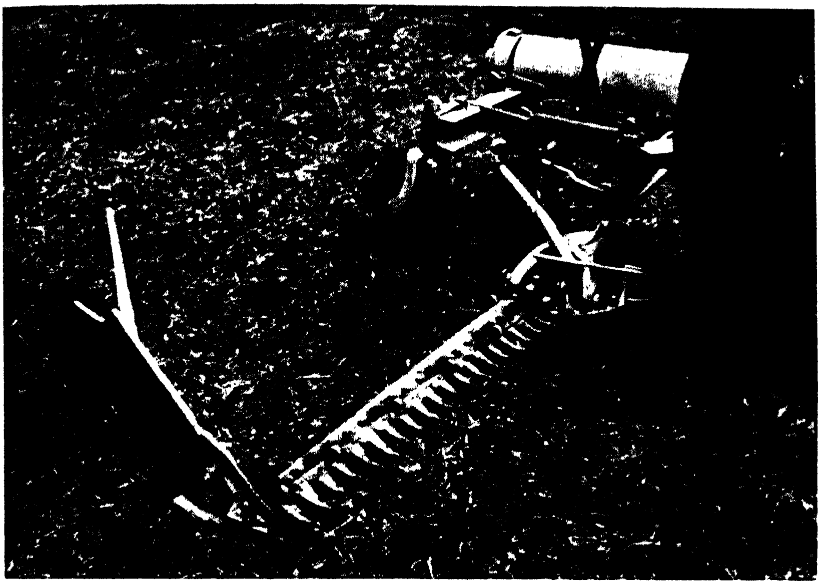
Adjusting the Concave.—The revolving drum beats the grain out of the ear by striking it against the concave, and it is of the utmost importance that the concave should be adjusted to suit the crop that is being threshed. If the setting is too wide the straw will pass out of the machine imperfectly freed from grain, while, on the other hand, too close setting produces violent concussion, and a proportion of the grain may be broken or badly bruised, while much of the straw may be broken up into cavings. The usual distance between the drum and the concave for threshing cereals is $1\frac{1}{2}$ in. at the top, $\frac{3}{4}$ in. at the middle, and $\frac{3}{8}$ in. at the bottom. A closer setting is generally necessary for damp grain because this is difficult to remove from the straw, but when the corn is dry and brittle a wider setting will give satisfactory results. With regard to the adjusting screws for the concave, it is important that the same number of turns should be given to the nuts on each side of the machine, and adjustment should never take place while the thresher is in motion.

Drums that have been in use for a considerable time become worn in the centre, where most of the corn is usually dropped, and when they are adjusted to give good results in the middle tend to crack the grains which fall towards the sides. Drums in this condition should have their bars renewed or straightened, and the concave must be given similar attention.

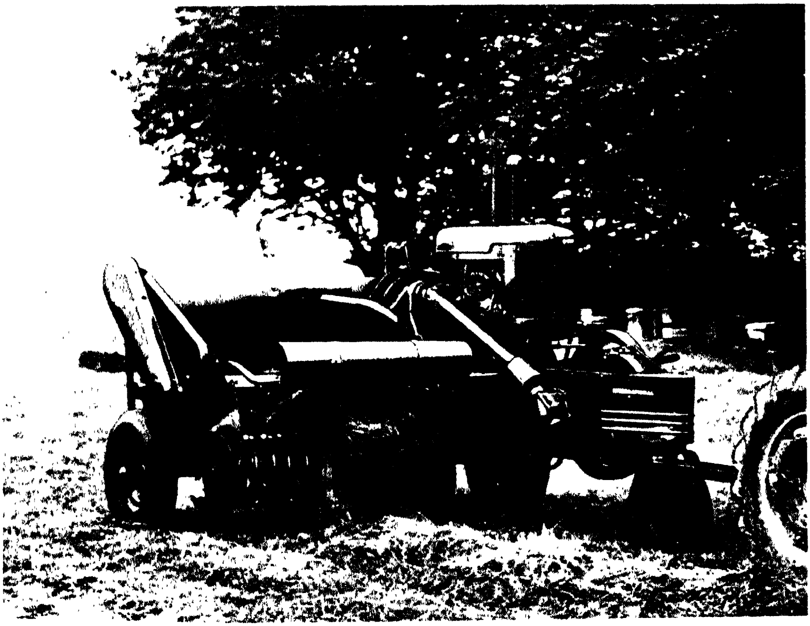
Regulating the Blowers.—The strength of the blast can be regulated by opening and closing the blower slides. When cleaning out the machine the blasts should be fully opened and the thresher run at full speed, empty, to clear the riddles, etc. The weight of the grain determines the strength of blast required, and adjustment should be made so that all the chaff, awns, and dust are blown away and yet no light grain is carried with them.

Selection of Riddles.—The object of the riddles is to remove pods, seeds, dirt, etc., from the grain, and it is important that suitable riddles should be fixed in the dressing shoes for the particular kind and quality of corn to be threshed. Large grains like oats require larger riddles than wheat, and wheat than rape. When the grain is a little damp larger riddles may be necessary.

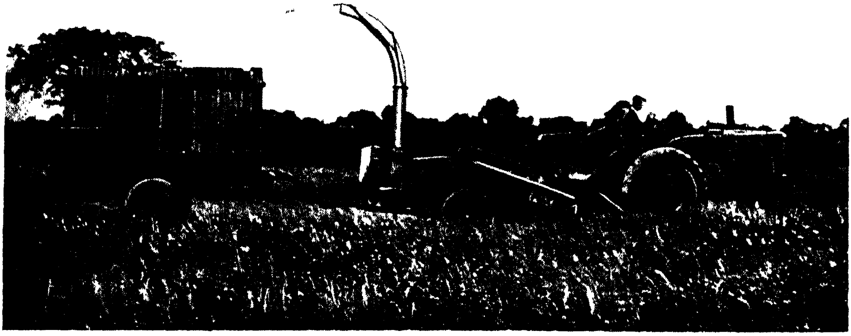
In the first dressing apparatus there is an upper (" capes " or " chob ") riddle which allows the grain and smaller rubbish to pass through but removes the " capes " (stones, pieces of stick, broken ears, and the like). Machines are provided with a selection of upper riddles to suit grain of different sizes, and the best is the



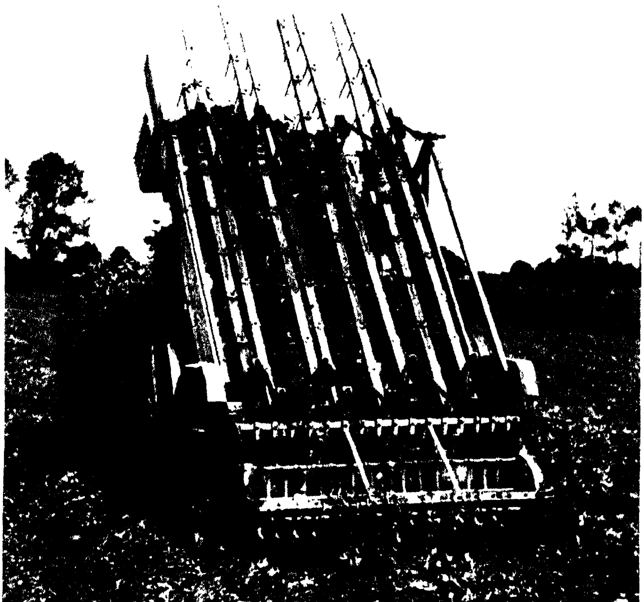
A. TRACTOR MOWER (BAMFORD)



B. ONE-MAN PICK-UP BALER (INTERNATIONAL)

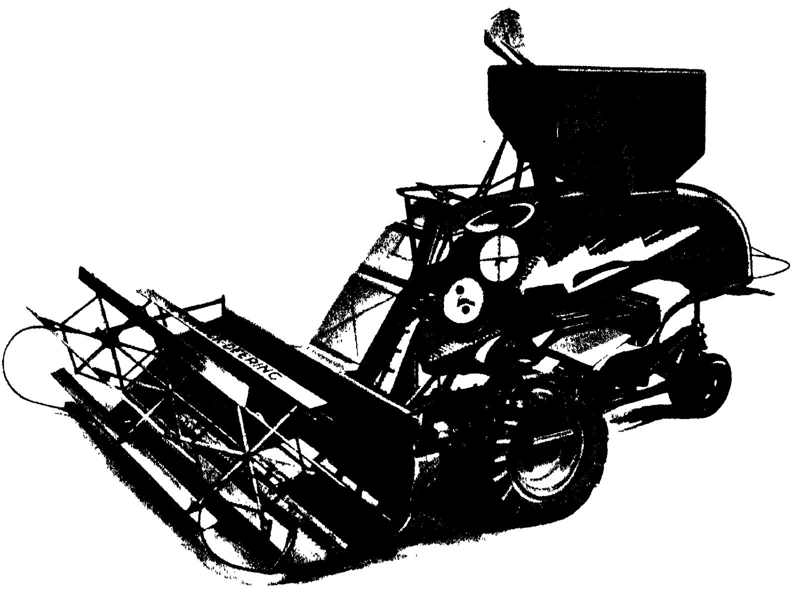


A. Green-crop Harvester (Fox Rivers)

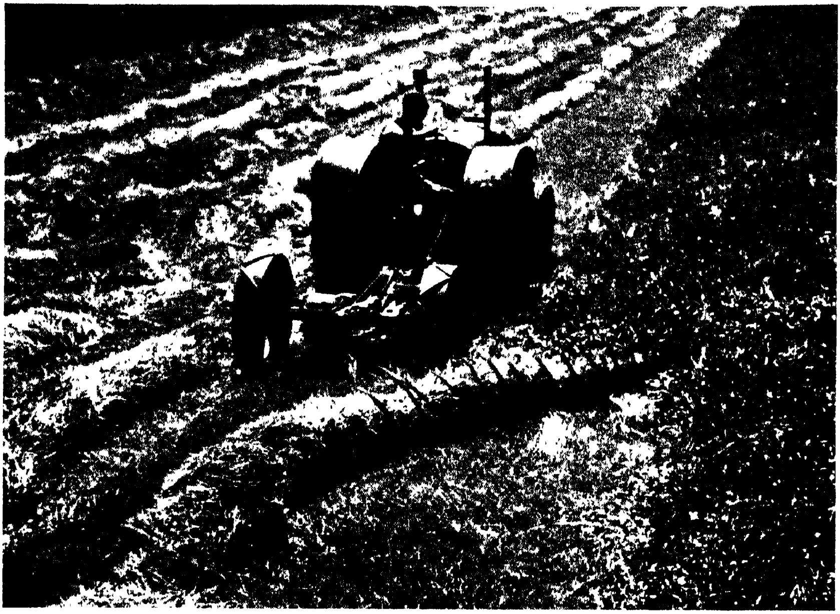


B. Green-crop Loader

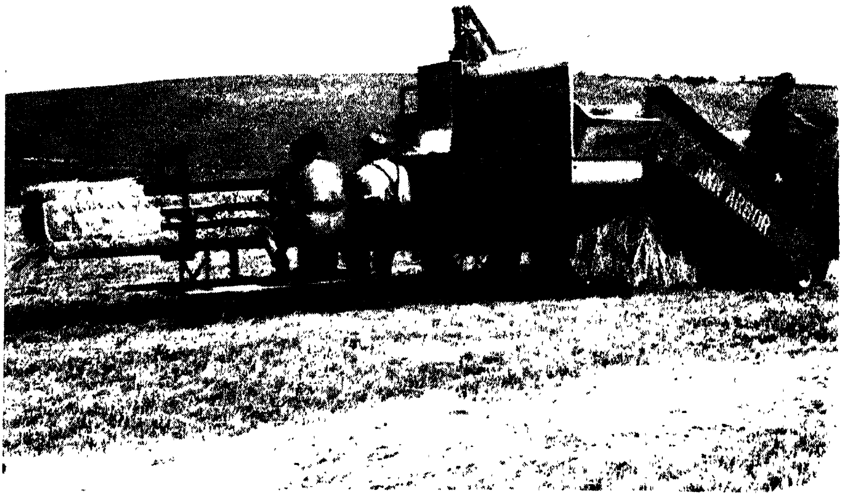
A. Small (6-ft. cut) Combine Harvester (International)



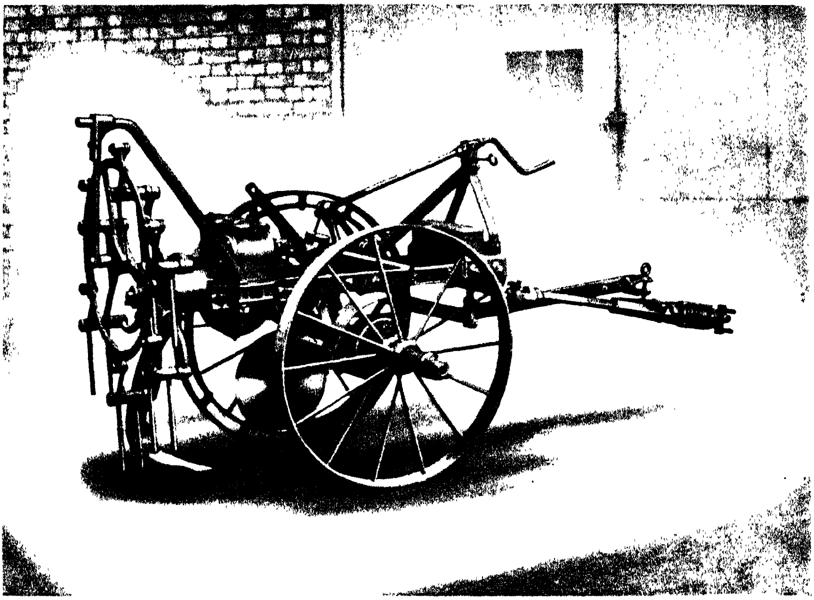
B. Section of Self-propelled Combine Harvester (International)



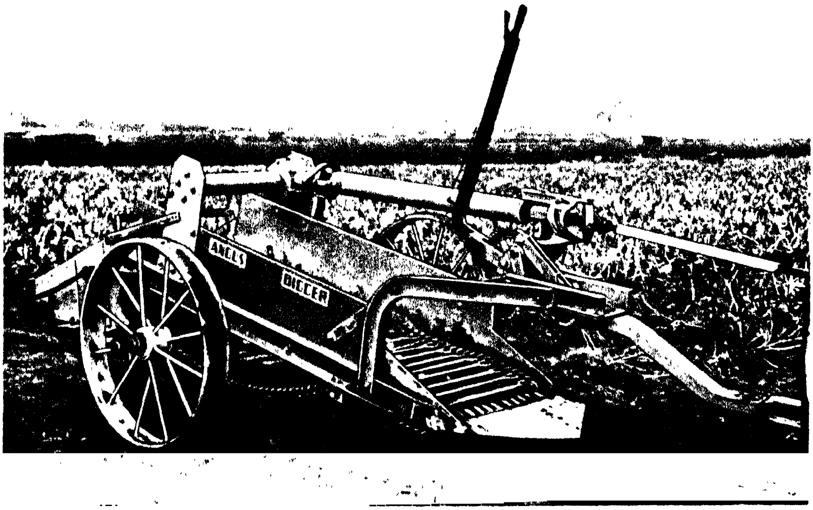
A. Swinging Windrower



B. Pick-up Baler at Work

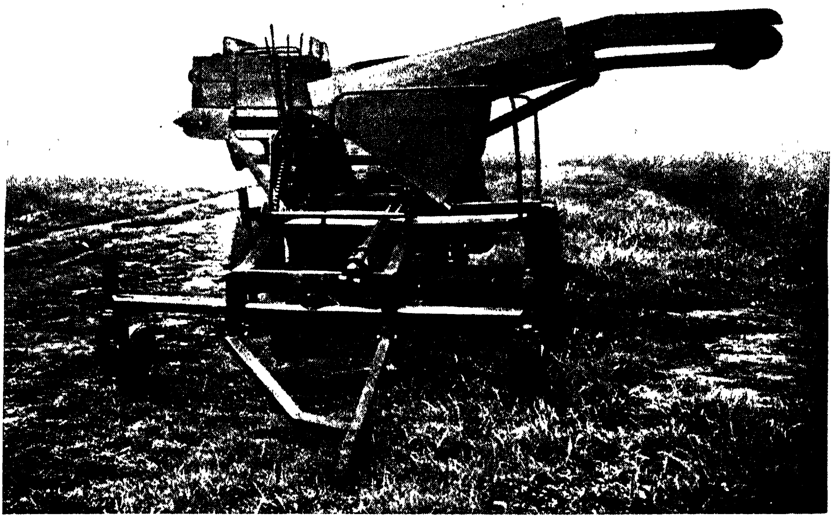


A. Fork-Action Potato Digger (Ransomes)

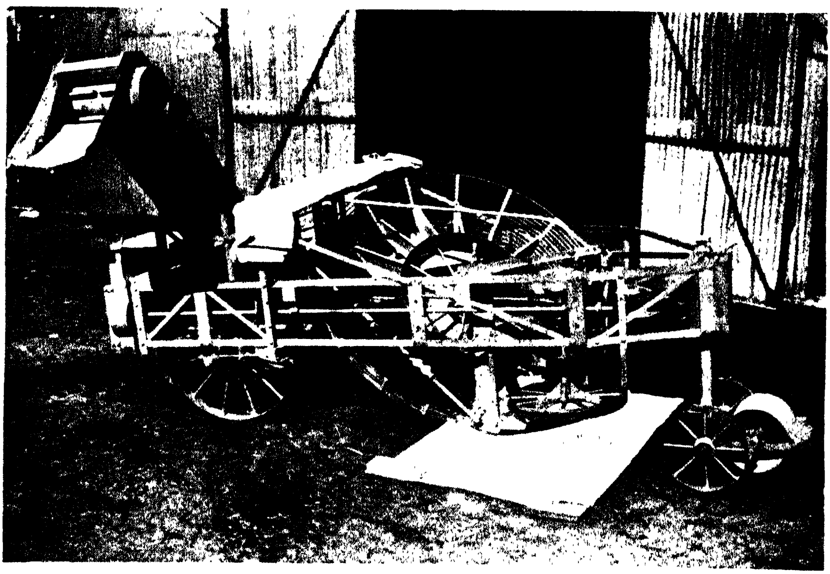


B. Elevator Type Potato Digger (L. O. Tractors)

PLATE XXII



A. Potato Harvester, Elevator Type, Front View, Showing Side Loader (Johnson)



B. Revolving Grid Type Potato Harvester (Packman)

smallest which will not pass the grain out with the capes. For example, $\frac{1}{4}$-, $\frac{5}{16}$- or $\frac{3}{8}$-in. mesh may be used for wheat, according to its size, while a $\frac{1}{2}$- or $\frac{5}{8}$-in. may be used for oats. There is also a bottom or seeds riddle which has a $\frac{1}{16}$- or $\frac{3}{32}$-in. mesh; this retains the grain and rubbish of similar size but allows dust and small weed seeds to fall out of the machine; it may be replaced by a blank plate when it tends to choke.

The second dressing apparatus is provided with two riddles, both of which must be changed to suit different types of corn. The upper has generally the same mesh as the capes riddle, and the lower has perforations $\frac{1}{16}$ in. less. The grain passes through both of these, and in so doing is subjected to the blast of the small blower and freed from dust, chaff, and broken awns. Material that is too large to pass is usually returned to the first dresser, but may be discharged through a tailings riddle and spout. In the bottom of the shoe there is a fine-mesh screen, and there may even be a third blower, to dress the grain further before it reaches the rotary screen.

A complete set of riddles is provided with each machine, and makers' instruction books give full particulars as to their use.

The Rotary Screen.—The rotary screen separates the material into tail corn, including weed seeds and seconds, and firsts or head corn; it delivers these to separate bagging spouts. The openings of the screen can be adjusted to suit different kinds of grain or to alter the relative proportions of head corn and seconds.

The Awner and Smutter.—These consist of a rotating shaft carrying a number of knives and bars which move in an iron cylinder or wire cage. The grain enters the end of the awner and is gradually worked through the cylinder owing to the "set" given to the blades, which cut the awns off barley; it next reaches the conical smutter, where beaters further free it from chaff, awns, and dust, and polish it. The severity of the treatment in the smutter may be adjusted by sliding the beaters to the larger or smaller end of the conical casing, thereby increasing or decreasing the clearance through which the grain must pass. In most makes, when less drastic treatment is required, the grain may be passed through the awner without going through the smutter.

Wet grain should not be put through the awner or smutter. If broken grain is being delivered, the grain should be examined as it leaves the elevator. If damaged at this point the concave

is set too close; if whole at this point the smutter needs adjustment.

Threshing Wheat.—When the proper riddles have been inserted wheat may be passed through the whole of the cleaning and sorting apparatus. Bunted wheat must not be put through the awner and smutter, which break up the bunted grains, liberating the spores and so spoiling the whole of the sample. If in a wet or soft condition wheat may be bruised in the smutter, and should therefore be passed from the elevator direct to the second dresser.

Threshing Oats.—The proper riddles, which are larger than those required for wheat, should be fixed, and a blank plate may have to replace the seeds riddle of the first dresser. Oats are seldom passed through the awner and smutter, as their action is likely to break and shell the grain. Occasionally, however, the smutter is adjusted to " clip " the oats by removing the chaffy ends. Where oats are wanted for feeding the grower's own live stock it is generally quite unnecessary to carry out the second dressing, so they are sacked direct from the elevator.

Threshing Barley.—It is particularly desirable that barley should not be " nibbled " or broken in threshing, because its value for malting purposes would thereby be greatly reduced. The sample must be carefully examined from time to time, and the concave and smutter adjusted at once if broken grains are being delivered; indeed, good malting barley is not often put through the smutter. The maltster does not object to a sample in which some grains carry parts of their awns.

Threshing Beans.—The concussion of the ordinary drum is too great for beans and causes a large proportion of the sample to be broken. For this reason most makers furnish special drums for pulse threshing. For moderate quantities, however, the drum may be made suitable by the removal of every second beater, or a larger pulley may be fitted to reduce the speed of the drum. The upper portion of the concave should be thrown right back and fitted with an iron plate—supplied as an extra by the makers—and the bottom portion should be lowered to about 1 in. from the beaters. Special riddles should be fitted to the first dresser and the beans should be delivered into sacks from the elevator. The feeding of the machine must be done carefully and slowly.

Threshing Small Seeds.—Adjustments can be made to the

standard thresher to enable it to deal with grass and clover seeds. For most grass seeds a piece of sheet iron is placed over the upper portion of the concave, the drum speed is reduced slightly, a special cavings riddle is fitted, special sieves are put in the first and second dressing shoes, wind blast is very carefully regulated, and the rotary screen is closed right up. If the awner and chobber are used they must be set correctly to prevent damage to the seed. The good seed comes out of the tail-corn spouts, and the unthreshed heads and other material from the other spouts are put through the machine again. Clover seed is first put through the standard thresher, when the unthreshed heads are collected from the first dressing shoe. A special "hulling" apparatus, consisting of a concave plate to fit over the ordinary concave and a set of clover riddles, is then fitted and the heads are put through the machine again. A second type of huller dispenses with the double handling of the clover heads. This attachment, consisting of a small drum rotating at high speed in a cylindrical wire screen, is fixed to the top of the thresher. It takes the clover heads from the first dressing shoe, "draws" the seed and passes it into the second dressing shoe, which has a special clover sieve. Large single-purpose hulling machines are available for dealing with large quantities of clover seed. They are normally in the hands of contractors.

The standard thresher can also be converted for threshing linseed and seed crops of brassicas, roots, and sugar-beet.

COMBINE HARVESTING

Harvester-threshers (Plate XIX), as their name implies, cut and thresh crops in one operation. They were first developed for harvesting in semi-arid regions where compact-eared cereals could stand for long periods in a dead ripe condition without risk of damage by weather. The machines were very large, and when owned by contractors they dealt with a big acreage during a long harvest period. More recently "farmer's combines" taking a moderate cut of 10 or 12 ft. have become very popular, and quite small machines with a cutting width of as little as 40 in. are now made. Harvester-threshers are being used to an increasing extent in the more humid countries. They have been running in this country for many seasons and, when used in conjunction with corn driers, have done very satisfactory work. While the maximum

capacity, of, say, a 10-ft. machine may exceed 3 acres an hour, the average output is generally about 2 acres an hour, and 1 acre per hour may be all that can be done in a long-strawed crop if a short stubble is desired. The season's output may be reckoned as so many acres per foot of cutter-bar. Working on average crops, a combine in the south of Britain harvests 30 acres per foot of cut during the season, but in the north, where the "combine-day" is shorter, the average is less, viz. 16 to 20 acres per foot.

The mechanism of the small combine is frequently driven from the power-take-off of the towing tractor; but on larger combines it is driven either by an auxiliary engine (the tractor being used for towing the machine) or, as on self-propelled combines, by its own large engine. The cutter-bar with the mechanism for conveying the cut corn to the drum is usually called the header. The smaller combines have a header with a canvas which takes the cut corn straight back from the cutter-bar to the drum. On larger machines with offset headers the canvas operates in the same way as that of a binder platform, taking the crop to one side into an elevator which leads to the drum. Wide headers on large self-propelled combines have right- and left-hand canvases which carry the crop on to a centrally disposed, horizontal slat conveyor running back from the knife to a vertical slat conveyor which feeds the crop into the drum. The canvases may be replaced by augers. Augers are unaffected by damp straw and have a longer life than canvases; but although they are satisfactory with medium and short straw they are not so efficient with long straw. The grain is separated and cleaned, and is then conveyed either to a grain tank or to a bagging apparatus; light weed seeds are blown out with the chaff, but the heavier pass through with the grain, from which they are sometimes separated and bagged. The straw is either left in a swath behind the machine, to be gathered later, if required, by sweep or pick-up baler, or is tied by means of a trussing or bunching attachment. Spreading devices are available to distribute the straw evenly on the stubble in order to facilitate ploughing in. With a heavy crop the tractor must be driven slowly to enable the thresher to keep pace with the bulk of the incoming material, especially if the header is wide and the machine is set to cut a low stubble. The labour requirement for a large tractor-drawn combine is a man for the tractor and a man for the control platform of the machine, but when

bagging is done at least one more operator has to be carried. On some of the smaller combines the control levers are so arranged that they can be reached by the tractor driver, when an operator on the platform is not required. The self-propelled type, when fitted with a grain tank, can be operated by one person. The grain has, of course, to be driven from the field, and where a tank is employed a truck run in below the grain chute can collect its load in bulk. If bags are used, they are dropped on the field in batches and have to be picked up later and loaded into wagons. It saves labour to use bags containing not more than 1 cwt. When a long stubble is left the quantity of straw is not large, and on a specialized grain farm it is sometimes left on the ground and ploughed in.

When the crop is not ripe enough for direct combining, or when it contains green and succulent weeds, it is sometimes cut and left in a windrow until the green material has withered and the grain has ripened. The windrowing is done either with a binder with the knotter out of gear (so that the crop falls off the deck in a continuous stream) or with a special windrowing machine which has a reel, a cutter-bar, and a platform canvas to deliver the crop to one side. A combine with a "pick-up" fitted in place of the cutter-bar and reel is used to lift the windrows and do the threshing. There is evidence that a cereal dries quicker in the windrow than when bound and stooked. It is important that the swath should be kept off the ground by a moderately long stubble; if the stubble is too long it will buckle and allow the heads of corn to come into contact with the soil. Combining from the windrow is a method often used for harvesting clover seed and linseed.

Grain Dryers.—In our climate the moisture-content of combined grain is usually too high for the grain to be stored without first being dried artificially. When wheat is regarded as fit to cut with a binder the moisture-content of the grain may be over 30 per cent.; when it is to be combined it must be allowed to stand until it is a good deal drier, but unless the moisture-content of the grain is less than 16 per cent. it will heat and go mouldy in store. Only in exceptional seasons is grain straight from the combine as dry as this. Several types of farm dryers are on the market. In most, hot air is blown through a thin layer of the grain to take away the surplus moisture, and the grain is then cooled by having cold air forced through it.

Dryers are usually divided into two classes: continuous and batch. A simple continuous dryer has a coke furnace to produce hot air without smoke, a power-driven fan to draw air over the fire and blow it through the grain, and a double-walled rectangular tower of perforated sheet metal. The space between the inner and outer walls is filled with grain, which falls slowly at a rate determined by the adjustment of the size of the exit at the base of the tower. Hot air is blown into the upper portion of the space between the inner walls and is forced outwards through the layer of grain; and cold air is blown into the lower portion to cool the grain. The three types of batch dryer are the tray, the platform, and the ventilated silo. The tray has a perforated floor on which a layer of grain of uniform thickness is spread, and through which hot air is forced upwards. The platform dryer consists of a hollow chamber, the roof of which has a series of openings over which are placed bags of grain usually 100 to 112 lb. in weight. Warmed air, normally about 25° F. above atmospheric temperature, is blown into the chamber and escapes through the grain. The simplest form of ventilated silo has a perforated or porous floor. In it the temperature of the air is about 10° F. above atmospheric, and drying proceeds gradually from the bottom of the silo upwards. Other forms of silo have air inlet and outlet ducts distributed at different levels, so that drying is faster in these than in the simple silo with a perforated floor. A barn or granary can be converted into a series of silos by erecting suitable partitions, and ventilation may be provided through ducts laid on the floor. Electricity or a coal-, coke- or oil-fired furnace may be used for heating the drying air; but when only relatively small temperature rises are required—as, for example, in platform dryers and some silos—the waste heat from the engine driving the fan and conveying equipment may be used. In one ventilated silo the drying air has its relative humidity reduced by passing it over silica-gel, which has the power of absorbing moisture quickly. The silica-gel is regenerated by passing over it very hot gases from an oil-fired furnace.

Although in practice it is not difficult to judge when the grain has been dried sufficiently, moisture meters capable of determining the moisture-content of grain rapidly are now frequently used. The temperature of the hot air is measured by a thermometer placed where the air duct enters the dryer, and is regulated by allowing more or less cold air to mix with the hot draught from

the furnace. If the grain is overheated it will be damaged, and the following temperatures should not be exceeded :—

Type of Grain	Maximum Temperature
Seed corn and malting barley, exceptionally damp (over 24 per cent. moisture)	110° F.
Seed corn and malting barley, moderately dry (under 24 per cent. moisture)	120° F.
Linseed, mustard, and other oily seeds	115° F.
Wheat for milling	150° F.
Oats and dredge corn, not for seed	180° F.

Some dryers are equipped with pre-cleaners for removing green stuff, such as fragments of weeds, which would otherwise slow down the drying process. If the green material goes through the dryer it is removed later by winnowing.

What are the advantages and disadvantages of this type of harvesting ? There can be no doubt that if the combine is given sufficient acreage to keep the overhead charges per acre down to reasonable limits—and this depends largely on the original cost of the machine—the cost of harvesting is greatly reduced, mainly because of the elimination of those operations, such as stooking, carting, and stacking, which have a high labour requirement. On the basis of about 200 acres of cereals, binder-thresher harvesting is probably 75 per cent. more costly than combine harvesting. Once a crop has been combined the grain is no longer liable to damage from unfavourable weather. This advantage is to some extent offset by the fact that a crop has to be left seven to ten days after it is binder-ripe before it is fit for the combine ; and during this period losses may occur through the crop going down, or through shedding in high winds. The combine will harvest more grain from a laid crop than a binder. The system has several disadvantages. A large combine is costly, and difficult to house and move from field to field. It is heavy, and it may be unsuitable for soft land in wet seasons. Small combines do not have these drawbacks, but neither are they so labour-saving as compared with older methods of harvesting. Losses may result when the threshing mechanism is tilted on uneven ground. Machines designed especially for hillside work are made, but they are not in common use in this country. Although it is possible to leave a short stubble and to collect the straw either by sweep or by a pick-up baler, there is usually, in practice, a considerable loss of straw. While this does not matter on a purely grain farm, it is a

disadvantage on a mixed farm where bedding is required for stock. Green weeds are not easily dealt with by the machine unless the windrowing method is followed. The wide adoption of the system in recent years has created a need (which was not fully met at the time of writing) for additional drying and storage facilities on farms.

THE STORAGE OF GRAIN

Grain that lies wet will sprout and waste, and damp grain will heat and mould in bulk. Thus, if a particular batch is deemed too moist for bulk storage, it must either be put through a dryer or spread out in a thin layer on a dry floor so that, with the aid of frequent turning and ample ventilation, it will dry naturally; but natural drying will make little or no progress if the weather is cold and wet.

It is sometimes necessary to store damp combine grain for short periods prior to putting it through a dryer. Heating and mould formation are prevented if the grain is kept in a bin with a perforated floor through which cold air can be blown. The upper layers of grain in a ventilated bin tend to collect the moisture driven off the lower layers; it is therefore necessary to turn it at frequent intervals. Turning is facilitated if a number of bins are used so that the storage capacity must be in excess of the bulk of grain. With a series of bins an extensive conveyor system is necessary for handling the grain. Pneumatic conveyors have many advantages over the more conventional bucket type: their initial cost is comparatively low; a single unit can convey grain in any direction and the conveying duct may include a reasonable number of bends; the fan is the only moving part; the position of the ducts is easily and quickly altered; and the system is self-cleaning. A disadvantage of pneumatic conveying is that it requires slightly more power per ton of grain handled than a bucket elevator.

In some parts of the country farms are provided with large well-ventilated granaries in which grain can be kept in bulk until used or marketed. The safe depth for the heaps depends on the moisture-content, "raw" material requiring to be more thinly spread than dry. If there seems to be any risk of heating, the grain must be examined frequently and turned at once if any perceptible rise in temperature occurs.

Wheat and oats can be kept in bins if their moisture-content

is less than 14 per cent., but barley should be a little drier—say 12 per cent. Grain silos are common at the ports and mills where large quantities have to be held, and, in the event of combine harvesting becoming much more common, the provision of similar storage may be required in grain-producing districts. Bins and silos have to be strongly constructed, because grain, like a liquid, exerts outward as well as downward pressure.

Grain can also be kept in bags, but this is a costly method of storage, and the bags are liable to damage by vermin. Sacks of corn must be protected from ground moisture as well as from rain.

HAY-MAKING MACHINERY

The process of hay-making and the use of hay-making implements are considered in detail in Part II (see Fodder Conservation); in this section it is necessary to give only brief descriptions of a few of the hay-making machines in common use.

The Horse-rake. — The horse-rake is used not only for dragging hay into windrows and raking over hayfields but is employed for raking stubbles after the principal harvesting operations have been completed. The construction of the rake is simple and can be clearly seen in Fig. 18. In the older types of machines the teeth were raised by means of a tilting lever when it became desirable to deposit the load, but in most new makes a self-lifting mechanism is incorporated, which, by means of a friction or pawl clutch brought into action by the pressure of a pedal, causes the wheels to raise the teeth and by this means frees the implement of its load. Side-delivery rakes may be used for gathering the crop into windrows, but these are generally combination implements with a number of different actions. A special wide rake for tractor haulage is now available; its wheels may be shifted on to secondary axles so that it can be pulled sideways through gateways and along roads.

The Swath Turner.—The swath turner is employed to turn over the herbage which has been left on the ground by the mower, so that it may receive further exposure to the drying action of air and sun; it does not ted the material in any way, and causes a minimum of damage to the brittle tissues. The principle of the turner, which is generally constructed to deal with two swaths, is to employ rotary forks which roll the hay into an inverted position as the machine is advanced. Fig. 19 illustrates a

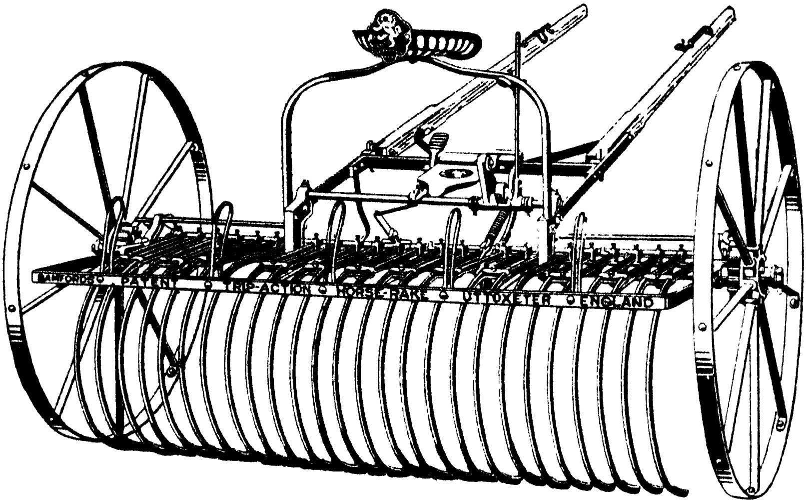


FIG. 18.—Self-acting Horse-rake

combination machine which with the centre sections of each rake removed is a swath turner, and with all the rakes complete is a

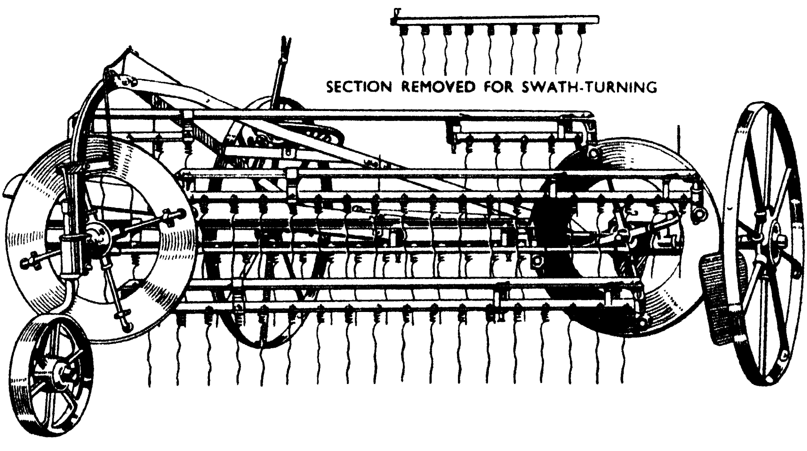


FIG. 19.—Combination Swath Turner and Side-delivery Rake (Bamford)

side-delivery rake for putting two or more swaths together to form a windrow. Other machines have independent forward and reverse gears to each set of rakes: they can turn the swaths to the right or left, or together so that they form small windrows.

A machine can be got to deal with 6-ft. swaths where a tractor mower of this width is employed.

The Tedder.—Fig. 20 illustrates a rotary tedder, which is used to ted and scatter the hay over the surface of the field, thus facilitating drying. For very thorough work the machine can be given a forward motion which carries the hay up under the guard and throws it backwards over the axle. For less drastic treatment the motion of the forks is reversed, and the material is tedded

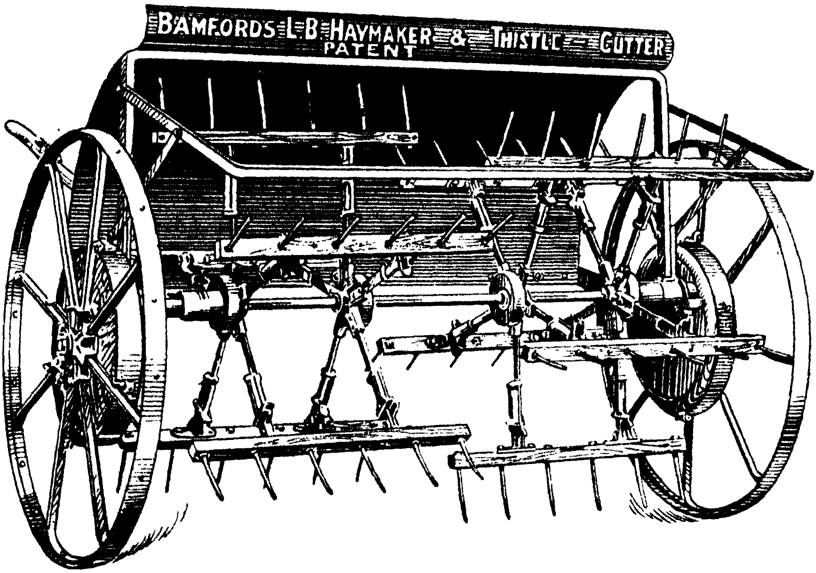


FIG. 20.—Hay Tedder (convertible to Thistle Cutter)

backwards without raising it far from the ground. Some makes of tedders have a kicking action, and spread the hay by means of their oscillating forks. All tedders tend to damage the herbage considerably and to leave it uniformly spread over the ground—a condition that renders it easily damaged by rain. The model illustrated can be converted into a thistle cutter by substituting blades for the forks.

A machine called an aerator, developed primarily for use in harvesting grass and clover seeds, lifts single swaths off the ground and with a very gentle action aerates them. This, like some swath turners and tedders, is driven from the tractor power-take-off.

In good weather drying is facilitated by crushing or bruising the crop as soon as it is cut. Crushing is done by passing the swaths between rollers, and bruising by a power-take-off-driven rotor carrying swinging beaters. Crushed and bruised material is difficult to handle in unsettled weather and for this reason it is unlikely that the practice, which is of American origin, will become widespread in Britain.

The Hay Loader.—The hay loader (Fig. 21) is a wheeled elevating gear which is attached behind the hay wagon or lorry. The elevating mechanism is either forks mounted on rake-bars

Fig. 21.—Hay Loader attached to Lorry

attached to cranked shafts, or an endless apron taking the hay off a cylindrical pick-up drum. A recently introduced American machine utilizes the cylindrical drum to raise the hay from the ground and rake-bars to elevate it on to the vehicle. The drive for the mechanism is taken from the wheels, and when the wagon is moved forward the hay is raked up, carried to the top of the elevator, and dropped on the wagon, where it is trampled and built by one or two men. The machine is useful for ordinary meadow hay, but causes a good deal of breakage and loss in the case of clover, lucerne, or leafy young grass and clover mixtures, in all of which materials the leaves become brittle on drying.

A pike- or rick-making machine consists of a hay loader delivering into a tall, inverted, dome-shaped metal cage. A

man or boy in the cage consolidates the hay as it falls from the loader, and when the cage is full it is turned upside down, so that the pike or rick falls to the ground. Doors in the wall of the cage are opened to allow the machine to move away from the hay, which is then dressed down in the normal manner.

Hay Sweeps.—Hay sweeps are really transporting rakes with long horizontal wooden tines; they are used for collecting hay that is in windrows or cocks and for dragging it to the point where the stack is being built; when they are reversed the loads slide off on to the ground. These implements save an immense amount of labour, but as they cannot be taken through gates or along roads they can be used only where the stacks are constructed in the field. When these large sweeps were first designed they were drawn by two horses, one hitched to each side. Sweeps can now be fitted to tractors or on the front of motor cars, the latter being better for returning quickly for a load. A sweep fixed to the back of a tractor, and capable of being raised clear of the ground, is used for transporting hay pikes and stooks of corn. Some of the smaller forms of "hay-drags" or "tumblers" require one horse only and are tilted to dump their loads.

The Stacker.—This is a device introduced from America, which enables a load of hay brought by a sweep to be elevated as a whole on to the stack. In the loading position it has long horizontal and shorter upright tines, and it rests on the ground like a large fork. The fork is anchored and pivoted at its base so that it can be swung from a horizontal to a vertical position. When in use, a load is deposited on the fork by a sweep, and a motor, pulling on a rope that acts through a system of pulleys and levers, swings the load upwards and pitches it on to the stack.

The Stack Elevator.—Elevators are constructed in the form of a sloping wooden gangway in the bottom of which are endless chains carrying transverse bars with upstanding teeth, which, when the gear is in motion, carry the hay or corn sheaves from the ground to the top of the stack. Elevators are telescopic, adjustable for height, and are usually worked by means of a horse gear or a small oil-engine.

The Horse-fork.—This is a form of crane used to raise hay from the ground or from a wagon to the stack. Special forks are required for seizing the hay, and these may be either in the form of a double harpoon or a four-tined grapple, which works on the

principle of ice-tongs. The fork works best when the hay is brought to the stack in wagons or by means of rick lifters and is thus well consolidated. When the horse, which is used instead of a windlass, has raised the material over the eaves of the stack, the grapple is released by the jerk of a cord and the load is deposited.

Pick-up Baler (Plates XVII, *B* and XX, *B*).—This is a machine with a pick-up and elevator, which, when pulled by a tractor along a windrow of hay, or of straw from a combine, raises the material from the ground, consolidates it firmly in the baling frame and, after the baling wire has been inserted and tied by the operators, pushes the bales off on to the ground, or on to a trailer attached behind. One-man outfits are also made in which the twine, which replaces the baling wire, is tied automatically by a knotter mechanism similar to that of a binder. Some of these balers are of the ram type which produce neat compact bales; others are press balers which produce loosely tied bales. The Rotobaler, in contrast with other machines, produces a "swiss-roll" type of bale which is prevented from unrolling by several coils of binder twine. The twine is not tied: one end is trapped in the bale and the other is pushed into the bale by hand after it leaves the machine.

POTATO MACHINERY

Potato Digger.—The rotary digger or "spinner" (Plate XXI, *A*) is provided with a very strong share which is dragged under the potato drill and completely loosens the soil and the tubers. The share is followed, in a fork-action machine, by a reel of revolving digging-forks, kept in a vertical position by means of a link-motion system, which throw the whole of the soil and crop at right-angles across the track and leave the potatoes on the surface. In the older type the reel carries rigid forks projecting radially from a centre boss. There are two types of screen that may be fitted to facilitate gathering. One, a flat open-mesh screen, hangs vertically to one side of the reel to prevent the tubers being thrown too far. The other is a cage-like structure in the shape of a truncated cone, open at both ends and with a wall of steel rods. The cone rolls along the ground with its end of larger diameter near the reel. The potato ridge is thrown into the cone by the spinner. Loose soil falls through the wall of the cone while the potatoes, together with stones and clods of similar

size, roll out of the end of the cone and are left in a narrow band on the ground. Another type of spinner digger has a reel of vertical tines revolving about a vertical shaft with an auxiliary (the spider) reel at the side to help separate haulm and weeds from the potatoes. This type has a stirring effect on the drill and is more gentle in action than the previous one.

The mechanism of the horse-drawn machine consists of simple gearing to transmit the power from the wheels to the revolving parts, and the necessary clutch to put the machinery in and out of action. A tilting lever is provided to put the share in and out of the ground, and to vary its depth according to the requirement of the crop. Another adjustment, rendered necessary by certain soil conditions, affects the alteration of the angle of the digging forks. Tractor-drawn spinners may be driven from their land wheels or from the tractor power-take-off. Direct-attached power-driven spinners are also available for tractor work.

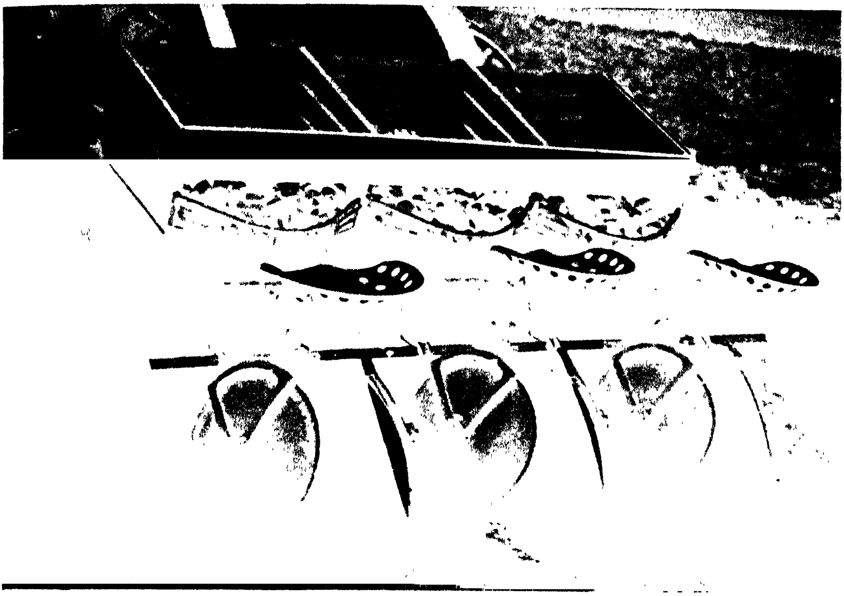
It is seldom that a potato digger works unsatisfactorily, but if the potato tops are heavy and green it may be necessary to scythe them down and remove them, or to destroy them chemically, to prevent persistent clogging of the share and also to prevent them from hindering the pickers. Again, when the share is worn it may be difficult to get the machine to work to its full depth, and many of the tubers may be sliced or left buried. This trouble is most common in dry seasons when the land is hard. The remedy is, of course, to have a new point fitted to the share.

The "elevator" digger (Plate XXI, *B*) is used on the lighter types of soil. It is usually a one-row machine drawn by a tractor and driven from the tractor power-take-off. Horse-drawn models, in which the drive is taken either from the land-wheels or from a small auxiliary engine, and tractor-mounted models are available. The machine consists of a scoop which is pushed under the ridge, and which delivers the soil and the tubers on to a moving endless apron built up of steel rods. This is agitated as it travels backwards so that the soil passes through to the ground. The tubers fall off the rear of the apron in a narrow row. On light land the elevator digger is superior to the spinner in that a higher proportion of the potatoes are exposed so that they may be more easily and more completely gathered. On heavier land, particularly under wet conditions, the elevator type is less efficient than the spinner because the agitated web is unable to get rid of the soil and this passes on to the ground

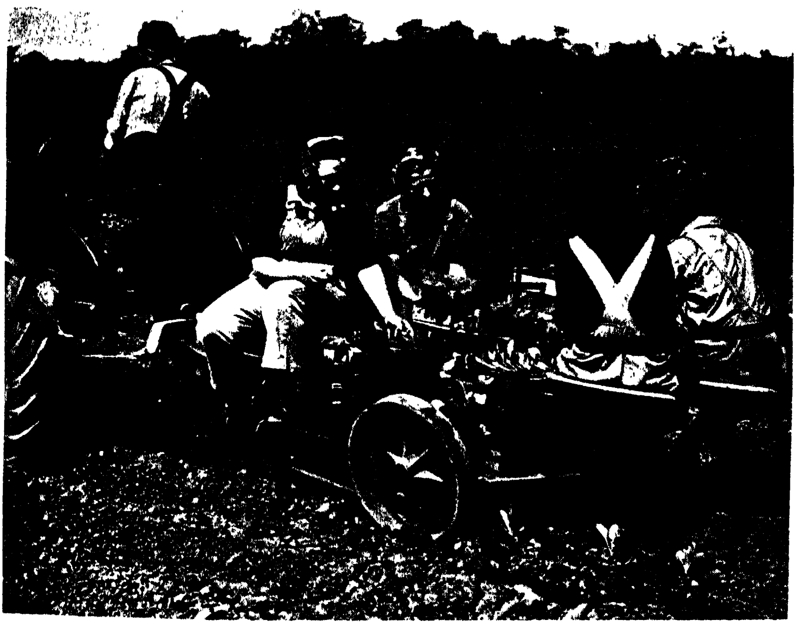
with the potatoes. Light abrasive soils, on which the elevator type is most efficient, cause rapid wear to the apron, rollers, and agitators. A large deflector can be fitted on the rear of the digger to move the potatoes to one side so that the machine can lift the next row before the previous one has been gathered. The same result is achieved at greater expense by fitting a cross conveyor on the rear. Picking and bagging platforms are sometimes attached to elevator diggers to allow up to six persons to separate the potatoes from the soil, haulm, weeds, and stones as they come off the digger. Two-row diggers have been recently introduced. It is claimed that a picker will handle more potatoes behind the two-row machine than behind the one-row.

The shaker digger has a pair of reciprocating grids set one behind the other instead of the elevator apron. The grids are not subject to the same amount of wear as the elevator apron and are less expensive.

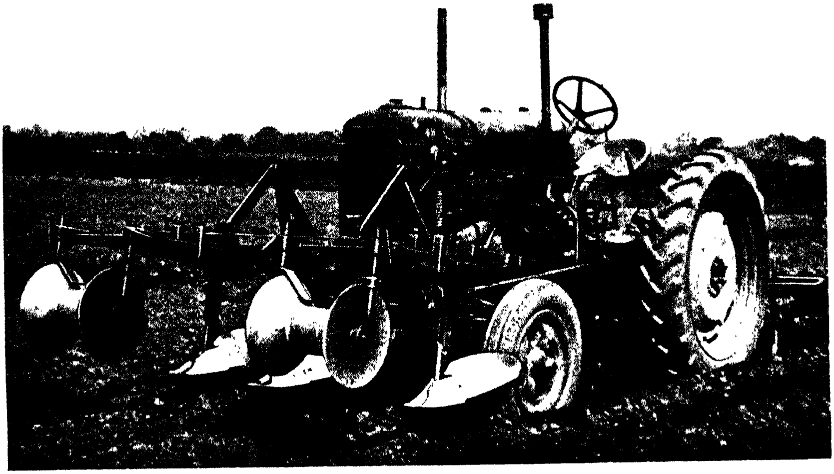
Potato Harvester.—A complete potato harvester lifts the crop, frees it from soil, stones, haulm, and weeds and elevates and delivers the potatoes undamaged into bags or vehicles. The complete mechanical separation of potatoes from stones and clods of similar shape and size, at an economical speed under actual field conditions and without damage to the potatoes, had not been achieved at the time of writing. The cleaning mechanisms found on existing harvesters—the agitated rod-link web (Plate XXII, *A*), a large, inclined, revolving, saucer-shaped grid (Plate XXII, *B*), a revolving drum, and a pair of rotating discs with radial projections, one behind the other on an inclined chassis—sift the contents of the potato drill so that only material over a certain size is retained on the machines. This material is a mixture of potatoes and extraneous matter, the final separation of which has to be done manually. Devices recently incorporated in existing British harvesters work on the principle that when potatoes and stones are dropped on to an inclined conveyor of special construction most of the potatoes bounce off while most of the stones stay on; these reduce the labour required for the final separation. A Swedish mechanical separator of great promise has a series of spaced rubber strips, kept under tension, in reciprocating frames. The stones fall through the strips, leaving the potatoes behind. With many types of harvesters haulm disposal is a difficult problem. Haulm pulverizers, consisting of high-speed rotors carrying metal blades or rubber



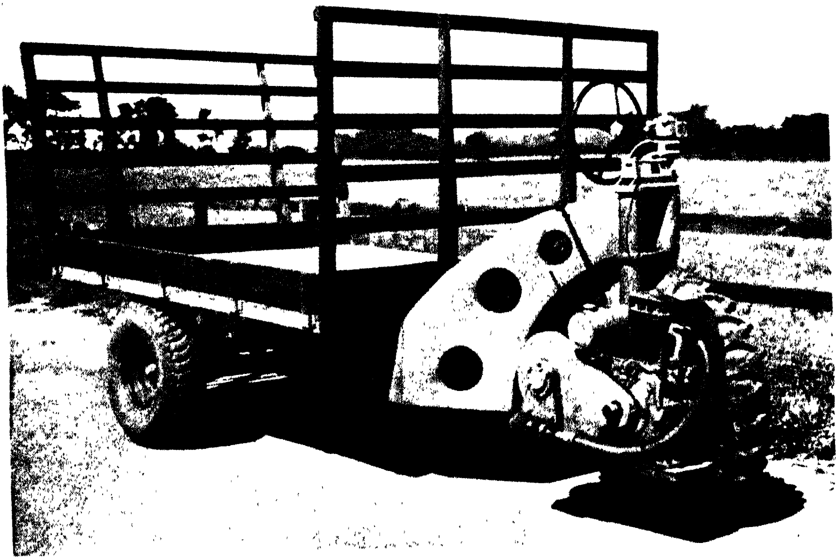
A. "Robot" Potato Planter



B. "Robot" Transplanter



A. Forward-mounted Tool Bar Arranged for Splitting Potato Ridges (Hudson)



B. Opperman "Motocart"

flails, have been developed. They precede the harvesters and break the haulm into very small pieces.

Potato Planter (Plate XXIII, *A*).—Many types of machine have been devised for potato planting. Some have been very elaborate, aiming not only at setting the tubers but also at forming and splitting the ridges in one operation. Others have been so simple that they were little more than light-wheeled frameworks from which the sets were dropped down spouts by the operators.

The spacing of the sets is usually done mechanically by either hand-fed or fully automatic devices. The commonest type of hand-fed mechanism is a series of cups on an endless belt which delivers the potatoes into the furrow. Other types include:—

1. A wheel with a channel-section rim divided into compartments by transverse metal sheets. One potato is placed in each compartment. The wheel may be large, in which case it revolves through being in contact with the ground, or it may be small and driven from the land wheels.

2. A wheel revolving on a horizontal platform in which is an opening above a chute leading to the furrow. The potatoes are placed between the spokes of the wheel, and as the wheel revolves they fall down the chute.

3. A series of cups hinged on radial projections from a horizontal turntable, and held up by a stationary circular platform which is incomplete at a point above the furrow. When the cups reach this point they swing down and drop the potatoes into the furrow.

4. On the Packman planter the cups are carried on arms radiating from a central hub. Mounted eccentrically with the hub, and carrying pins that engage with the radial arms, is a circular guide the purpose of which is to bring the cups close together at the feeding position and to space the cups at ground-level so as to give the required setting distance.

The most popular automatic device consists of an endless chain which carries cups up through the potatoes in a hopper. Each cup picks up a potato and conveys it down a chute into the furrow. This mechanism works reasonably well with closely graded seed, but with irregular seed the number of "misses" and "doubles" is high. To prevent misses the McCormick planter is equipped with a hand-filled reserve tray which automatically releases a potato into any empty cup. On the two-row

Teagle planter an operator fills the empty cups and removes the second potato in doubles.

Another automatic device consists of a series of spiked radial arms. As the arms revolve through a trough situated below the potato hopper they impale potatoes, carry them round and release them into the furrow. Both hand-fed and automatic spacing devices can be adjusted to give various spacing distances, usually by putting sprockets or gears of differing sizes in the drive from the land wheels.

Most American planters are fitted with distributors for the accurate placement of fertilizer in relation to the position of the seed. Some British planters also have fertilizer distributors but accurate placement is not always attempted.

Planters may work " on the flat " or on previously ridged land. For planting on the flat, one- and two-row machines can be used only if later inter-row cultivations are to be done one row at a time; a three-row planter is necessary if a three-row tool-bar is to be used for the subsequent cultivation. On the other hand, one-, two-, or three-row planters can be used on previously ridged land, and can be followed by three-row cultivators provided that the ridges have been made accurately—preferably with a three-row ridger.

One of the latest potato planters is mounted on the back of the tractor; the spacing mechanism is driven from the tractor power take-off and the whole machine is raised and lowered on the power-lift.

Potato Sorter.—Before the introduction of the mechanical sorter, potatoes were separated into various sizes by passing them over hand-riddles, which are still used to some extent in conjunction with light iron frames.

A modern sorter, such as that illustrated in Fig. 22, separates the material into ware, seed, chats, and dirt by passing it over oscillating grids and riddles. The two main riddles are removable, and are supplied in many different sizes. The most common mesh for a top riddle, which removes the ware from the rest, is from $1\frac{5}{8}$ to $2\frac{1}{4}$ in., and that of the bottom riddle, which removes the seed from the chats and dirt, $1\frac{1}{4}$ in. A conveyor is provided which carries the ware to the bagging apparatus and is long enough to allow one or two operators to look over the tubers as they pass and to remove all that are malformed, damaged, or affected by disease. The power is transmitted from the hand-crank to the

oscillating riddles and conveyor by means of a chain and counter-shaft, but many of the larger machines are ordinarily equipped with a small internal-combustion engine, the complete assembly being mounted on wheels to facilitate movement. The wires of the riddles may be covered with rubber to avoid damaging the potatoes. Another type of sorter has a rotating cylindrical riddle. The wall of the cylinder constitutes the riddles and is made of removable sections. As potatoes pass through the cylinder chats fall through the first section and seed through the second, while ware passes out at the end. The machine may be hand- or

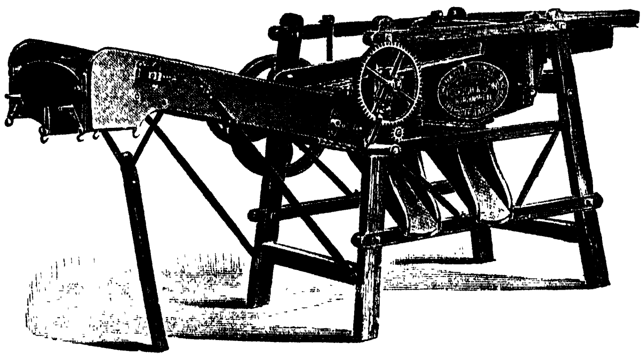


FIG. 22.—Potato Sorter (Cooch)

power-driven. Sorters should be as low as possible to facilitate filling and they must be easily portable as they have to be moved frequently in the course of a day's work. Some large sorters have a special feeding elevator which reaches from ground level to the riddles. The quantity of potatoes that can be dressed in a day depends very much on the presence or absence of disease and sprouts, and, of course, on the size of the machine; the larger power-operated farm machines may dress from 12 to 18 tons a day. The large sorters sometimes used in potato storage houses have a higher capacity.

An American sorter has a grading unit quite different from any of the British riddles. It consists of a series of specially constructed rubber rollers. Each roller is made up of several diabolo-shaped sections mounted on a common shaft. Two or more of these rollers placed side by side form a series of holes the size of which can be regulated by moving the rollers either closer together or farther apart. Each machine has two sizes of diabolo-

shaped sections—one for removing chats and the other for seed. All the rollers turn in the same direction and move the potatoes along as they do the grading. Chat and seed conveyors project laterally from beneath the grader, while the ware conveyor projects in line with the grader. All conveyors are rubber belts. The extensive use of rubber in this type of sorter means that the potatoes being dressed do not come into contact with any metal components and the risk of damage is thereby reduced.

TRANSPLANTERS AND ROOT HARVESTERS

Transplanters.—Machines have been designed to plant cabbages, cauliflowers, and other species that can be raised in a seed-bed for transplanting purposes. The machines are usually tractor-drawn, because only with a tractor is it possible to get that slow steady pull which allows the operators to work rhythmically. They are provided with trays or boxes to hold the supply of plants, seats for the operators who feed the planting gear, and fittings which open a furrow, set the plants in position, and firm the soil about the plant roots. In addition, they may be provided with a means of supplying water and fertilizer to each plant as it is set in the ground.

The simplest type of transplanting unit, the Quickstart, has a sledge-type frame which carries an A-shaped furrow opener, seats for two operators, and two press wheels in the form of a V to firm the soil. The plants are placed in the open furrow by hand and the spacing is therefore dependent on the efficiency of the operators. Two or more of these units may be used together to give a tractor a more economical load; or simpler, though similar, units may be mounted on a rear-attached or underslung tractor tool-bar. The Ritchie "Easy Feed" attachment for the Quickstart type of transplanter is a pair of rubber discs placed between the furrow opener and the press wheels. The operator, instead of putting the plants in the ground, inserts them between the rubber discs, and thus has a more comfortable feeding position. The discs carry the plants round and release them when the roots are in the open furrow.

The machine illustrated in Plate XXIII, *B*, is made by Transplanters (Robot) Ltd. It has seats for four operators, who feed the plants into rubber-protected metal fingers, which close and hold the plants and carry them by means of an endless chain

to the ground prepared by the furrow-opener. The fingers release the plants just as the furrow is being closed by the converging roller wheels that are placed behind the delivery point. With four workers feeding the machine and one driving the tractor, the planter is said to be able to set 12,000 plants an hour. Obviously, however, the number of plants set per hour and the acreage covered per day will depend on the speed of the tractor, the dexterity of the workers, and the distance between the plants. A lever is provided to disengage and raise the planting gear for turning on the headlands. The main wheels can be set to suit rows of different widths and the distance between the plants can be varied by an adjustment on the gear-box. The depth of planting can also be controlled.

Sugar-beet Harvesters.—A complete sugar-beet harvester should top the beets correctly, lift the roots completely, clean them so that soil is not sent to the factory, and either elevate them into vehicles or leave them on the ground in such a way that they can be easily loaded. The tops, too, must be kept clean enough to be suitable for stock feeding. The most efficient topping mechanisms are those which work on the beets while they are still in the ground. The topping unit has a device which rides on the crowns of the beets and adjusts the height of the topping knives for tall and short plants. This device may be a power-driven track, or power-driven wheels, or land-wheel-driven wheels, or simply a series of backwardly directed fingers. The knives may be two freely rotating discs, or two power-driven discs, or a single power-driven disc, or again a stationary blade. Some machines top the beets after they have been lifted. Most harvesters lift the beets with conventional shares, but those that top after lifting pull the beets out of the ground by their tops. One American machine impales the untopped beets on spikes which are carried on a large-diameter wheel. The cleaning device may be a series of tined knocker-bars, a revolving drum, a set of agitated slats, or a large-diameter screw working in a trough.

The crop may be harvested in one or two stages. In two-stage harvesting the topper, which may deal with one or several rows at a time, goes over the crop first and disposes of the tops in one of three ways. It may leave them lying on the ground as they are removed from the roots, in which case a further operation is necessary to move them out of the way of the lifter; or, if the topper has an elevator, it loads the tops into a vehicle without letting them touch the ground; or again, if the topper is followed

immediately by the lifter, it may have a windrowing device which puts the tops in rows on cleared land where they will not be run over by the trailers taking the roots from the lifter. The lifter may load the roots direct into trailers or it may leave them in heaps or windrows on the ground. In one-stage harvesting the topping and lifting mechanisms are incorporated in a single outfit. A few machines leave the tops spread evenly over the field in a suitable condition for ploughing in, but trodden into the soil by the carting-off vehicles and therefore not always clean enough for folding off. Nowadays most machines attempt to keep the tops clean enough for stockfeeding. The easiest means to this end is to leave the tops and roots lying separately on the ground in heaps or windrows. The roots may be heaped at intervals across the field, or, where the machine has a rear elevator delivering into a towed trailer, large heaps may be made on the two headlands with a third large heap in the centre of the field if the rows are very long. Most harvesters are tractor drawn, the mechanism being driven from the tractor power-take-off or by an auxiliary engine. A few are tractor-mounted, and a German machine is built on a self-propelled tool chassis. Some of the simple two-stage harvesting equipment has its mechanism driven from land wheels and can be either horse or tractor drawn.

It is possible to use mechanical pick-up loaders to lift beets from neat and orderly windrows and put them into vehicles. The loaders so far used in this country are constructed on the same principle as an elevator digger, with a rotating cranked bar replacing the share and with a side-delivering elevator. Some green crop loaders can pick up sugar-beet tops.

In Denmark a simple type of implement for topping and raising turnips and swedes is in widespread use, but the quality of the work done is scarcely good enough to satisfy British farmers. In particular, numbers of the roots are topped too low and in consequence are liable to rot during subsequent storage. A simple British machine has topping knives mounted on a floating sub-frame suspended from the main frame, a tailing knife, and arms for deflecting the roots to one side. Two models are available: one, for working on the flat, is mounted on angle-iron runners, and the second, for ridge or flat work, is mounted on four small wheels. As the machine is pulled along the row, feelers adjust the position of the knives, both vertically and horizontally, for correct topping. Although the topping and tailing are reasonably

well done the result is not as good as that done by a skilled hand worker. Maincrop carrots are sometimes harvested with the elevator potato digger and occasionally with the complete potato harvester embodying the elevator principle. The carrots have to be grown in row-widths suitable for the machine.

BARN MACHINERY

The Chaff Cutter.—Chaff cutters are made in almost all sizes, from small hand machines to large power cutters which are capable of dealing with material as fast as a worker can pitch. The chief working parts are a large flywheel, which has steel cutting knives fixed to its spokes, a self-feeding arrangement to carry the hay or straw to the knives, a change-speed gear which allows the material to be cut into different lengths, and a clutch to put the mechanism in and out of gear. Cutters are sometimes used in conjunction with threshing machines, receiving the straw from the shakers, cutting it, and delivering it into bags. Large-power chaffers are usually fitted with an apparatus which frees the material from dust. A medium-sized, self-feeding chaff cutter is illustrated in Fig. 23.

Grinding Machines.—Grinding mills should be capable of producing any degree of fineness, from broken beans to cereal flour. In a modern plate machine the process begins by passing the material through the "cracking cones," which produce fragments that are easily ground between the revolving grinding plates. These plates are held together by the pressure of a spring, the compression of which can be varied, according to the fineness of the meal required, by the adjustment of a screw. Should a piece of stone or metal get into the machine the spring will yield and prevent the plates from being scored or damaged. A roller mill does not grind the material but simply rolls it out flat, and is most largely used in the production of crushed oats for stock feeding.

A hammer mill can be used not only to deal with grain but also to pulverize materials as dissimilar as hay and chalk; it can produce "Sussex oats." As compared with a plate mill it works on quite a different principle: it has a high-speed rotor which carries swinging or fixed hardened steel hammers that break the grain or other material by impact only. The exit for the ground material is a screen placed just outside the hammers. Screens of

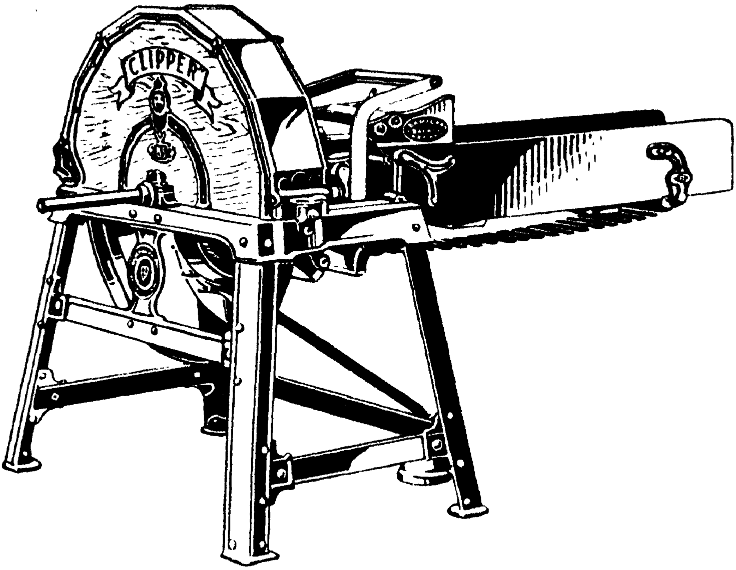


FIG. 23.—Power Chaff Cutter

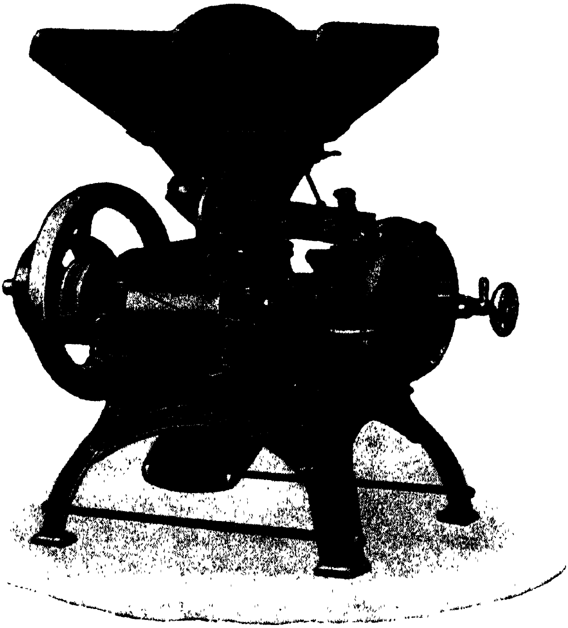


FIG. 24.—Combined Grinding and Crushing Mill

various sizes can be used to determine the fineness of the issuing material, which is blown into a collecting cyclone from which it can be bagged off. Hammer mills are expensive and have a high power requirement.

Root Cleaners and Cutters.—A root cleaner is designed to remove the adhering earth from mangolds, turnips, etc., and is

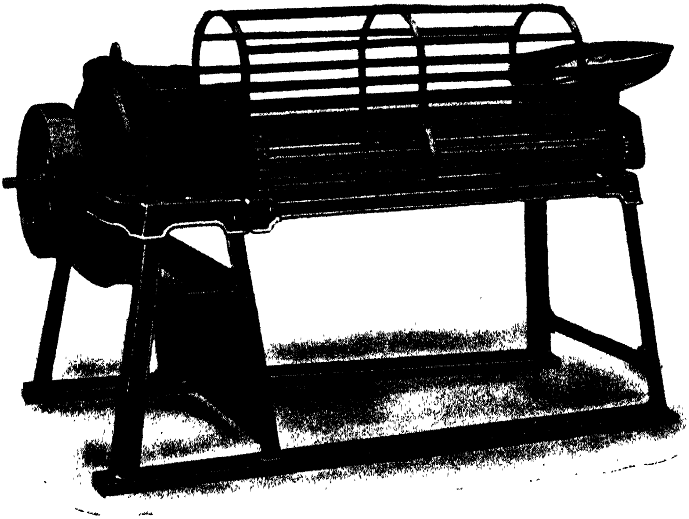


FIG. 25.—Root Cleaner and Cutter (Bamford)

usually built in the form of a revolving sparred drum. As the roots pass through this drum they are agitated and scraped, and the dirt falls between the spars to the ground below. The drum can be elevated or depressed at one end by means of a screw, and consequently the speed with which the roots pass through, and the thoroughness of their treatment, can be varied according to their condition. Cutters are made in several different forms, and may either slice the roots or cut them into fingers of various lengths, the work being performed by slicer knives or finger-piece cutting discs (see Fig. 25). Turnip-cutters may be fitted to carts, and can be used for automatically cutting and distributing roots on grassland.

Cake Breakers.—Oilcake as received on the farm may be in the form of long flat cakes, which must be broken up before being fed to stock; the size of the fragments has to be varied for different kinds of animals. A simple cake-breaking machine soon pays for

its cost in economy of time. The essential parts of a breaker are a framework, two toothed rollers connected up to the driving apparatus by suitable gearing, and an adjusting arrangement whereby the rollers can be set to produce material of any desired degree of fineness. This implement is becoming less necessary

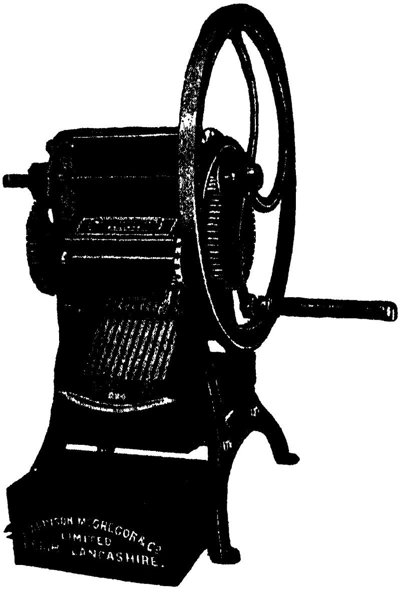


FIG. 26.—Oilcake Breaker

with the growing tendency of feeding-stuff firms to supply concentrates in the form of cubes or "nuts."

Winnowers. — The farm winnower is used mainly for dressing seed corn and malting barley. Combine-harvested grain is usually dressed by a more elaborate dressing machine worked in conjunction with the dryer. Milling grain as it comes from the ordinary thresher is normally well enough dressed for sale. The winnower is a series of reciprocating sieves on to which an air blast from a fan is directed. The wind blast removes the lighter grains and the sieves remove small and shrivelled grain and weed seeds. The severity of the dressing is varied by adjusting the wind blast and the screen sizes.

Seed merchants use dressing machines much more elaborate than the farm winnower for removing those weed seeds which are very similar in size to the grain or seed in which they occur.

Seed Dusters.—Most seed merchants dust their seed corn with an organic mercury dust before sending it out. There are occasions, however, when a farmer wishes to use his own seed and has the dusting to do himself. An old " end-over-end " butter churn is satisfactory for treating small quantities; the grain and an appropriate amount of powder are put in the churn and the handle is turned for some minutes. For the treatment of larger quantities it is advisable to use one of the special machines designed for the purpose. The simplest is the " Cascade," in which there are no moving parts. The grain and powder are allowed to fall down through the machine, and the grain, when it reaches the bottom, is covered with a film of dust. Larger machines usually have a slightly tilted revolving cylinder into which the grain and dust are fed continuously from hoppers.

Cutter-blowers.—The cutter-blower is used in silage making to chop the green material and blow it into a silo. Most machines are similar to a chaff cutter with the addition of a fan and ducting to take away the chopped material. Two types of cutting mechanism are employed—the flywheel type and the cylindrical type, which last is similar in principle to a lawn-mower. The fan blades are attached to the flywheel, but with the cylindrical type the cutter and fan are usually quite separate, with independent drives. It is advisable to have a tractor with a considerable reserve of power to drive the machine in order to eliminate the risk of blockages in the ducting leading into the silo. In some small cutter-blowers the fan is replaced by an ordinary elevator. The machine may be equipped with an attachment to feed molasses into the cut material. Lacerating and shredding machines, sometimes with and sometimes without special fans, are used to put green crops into tower and pit silos (see p. 504).

Where chopped material is delivered from a forage harvester a simple blower is used to convey the chopped material into the silo. Such machines have a feed-trough into which the loads of greenstuff from the forage harvester are tipped. A slatted chain or an auger conveyor feeds the greenstuff into a fan which blows it up the ducting.

Grass Dryers.—When grass in contact with air is neither losing nor gaining moisture a state of equilibrium exists between the moisture in the grass and the water vapour in the air. The amount of water vapour in air is usually expressed in terms of relative humidity, *i.e.* the ratio of the water vapour it contains

to the amount required to saturate it. If the relative humidity of air is reduced below the equilibrium point, moisture will pass from the grass to the air; and if the air is continually renewed the grass will get progressively drier until it approaches a moisture-content that would be in equilibrium with the air. This is the principle of all dryers, whether for grain or for grass. The relative humidity of air can be reduced by removing moisture chemically, *e.g.* by silica-gel, or by refrigeration, or merely by raising its temperature. The amount of water vapour required to saturate a given volume of air increases rapidly with temperature; hence the usual commercial method of drying grass is to treat it with air whose relative humidity has been reduced by heating. Oil and coke furnaces are normally employed. Drying of grass takes place in two stages. In the first the rapid evaporation of the water from the surface of the grass keeps it cool. In the second, moisture has to diffuse through the grass tissues to the surface before it can be evaporated, and the drying rate therefore falls. Where high drying temperatures are used in the first stage the grass will escape damage provided there are means of removing it as soon as it has lost its surface moisture. The means must be selective, because leafy material passes through the first stage more quickly than stemmy material. The second-stage drying must be done at comparatively low temperatures. But the whole drying process may be done at low enough temperatures to obviate risk of scorching. The temperature of the inlet gases in low-temperature dryers is 220° to 300° F. In high-temperature drying it may be 1000° F. or more. The amount of water to be evaporated from grass samples with initial moisture-contents of 80, 70, 60, and 50 per cent., for each ton of finished material with 8 per cent. moisture-content, are respectively 3·6, 2·1, 1·3, and 0·8 tons. Preliminary wilting of the grass thus greatly increases the capacity of a dryer. There are, however, practical difficulties in the way of wilting. The chief of these is the difficulty of getting a uniformly wilted product. Grass is usually dried down to a moisture-content of 10 per cent. for baling and 7 to 8 per cent. for grinding in a hammer mill. By drying down to 10 per cent. for baling the risk of damp patches (with the critical moisture-content of 15 per cent.) is negligible. On standing, dried grass comes into equilibrium with the atmosphere, when its moisture-content may be about 15 per cent., at which level it keeps satisfactorily. At any much higher moisture-content mould will develop.

Tray Dryers.—A tray dryer has one or several trays with perforated floors on which the grass is placed and through which air, at about 300° F., is blown upwards. In the simple one-tray dryer the air, after passing through the grass, escapes into the atmosphere, *i.e.* there is no recirculation. This limits the efficiency of the dryer. (The efficiency of a dryer is usually given as the fuel consumption in British Thermal Units per lb. of water evaporated.) The chief advantages of this type are its relatively low initial cost, and the simplicity of its operation. In multi-tray dryers there is recirculation of unsaturated drying air. The air that has passed through the almost-dry grass is collected by a metal hood over the tray, is then passed through another tray containing fresh wet grass, and is only then allowed to escape to the atmosphere. The I.C.I. dryer has four trays side by side which are used together in pairs—while one pair holds grass that is being dried the other pair is being charged. Of the pair being dried, the inner one has grass in the final stages of drying and the outer one wet grass. A hood over the inner tray collects the drying air after it has passed through the grass and mixes it with hot air from the furnace. Air passing through the outer tray escapes. When drying is complete in the inner tray of one pair the hood is moved over the inner tray of the other. The dried grass is removed and the partly dried material in the outer tray is teased out and transferred to the inner tray. Fresh grass is put in the outer tray. While this is being done the other two trays are being dried. The Fewster tray dryer has six trays which together form a hexagon which can be revolved, so that each tray in turn receives the drying air direct from the furnace. Four of the six contain grass being dried, that next to the furnace containing material in the final stages. Air passing through this is collected and passed downwards through the adjacent tray and finally upwards through the next two, which contain wet grass. Of the remaining two trays, one is being emptied of dried material and the other is being charged with wet. Tray dryers are dual-purpose—they can be used for grass and grain.

Conveyor Dryers.—In conveyor dryers hot air is blown through a thin layer of grass as it is carried through a drying chamber. The dryers are so designed that unsaturated air leaving the almost dried grass is re-used on the wetter. In single conveyor dryers this is achieved by having the drying chamber divided into sections, and by mixing the exhaust air from the "dry section"

with fresh inlet gases before forcing it through grass in the " wet section." At least two hot-air fans are thus required. In multi-conveyor dryers the conveyors are arranged one above the other. Wet grass is fed on to the top conveyor. Partially dried grass falls from the end of this on to the lower conveyor, which travels in the opposite direction, and this process may be repeated with additional conveyors. The drying gases are blown through the grass from below, and the speed of the conveyors is so adjusted that when the grass falls off the lowest conveyor it is dry. With conveyor dryers great care has to be exercised in order to get the material evenly spread on the conveyors. Self-feeders have been designed for this purpose.

High-temperature Dryers.—For tray and conveyor drying, grass is generally handled in the long state. For high-temperature dryers it has to be chopped. Here the drying takes place in two or three stages. In the first, which is done either in a tower or in a revolving drum, extremely high temperatures are used. The chopped grass is fed into the stream of hot gases at the base of the tower or at the inlet end of the drum. There are baffles in the drum to prevent the material from being blown straight through, and there are vanes on the inner surface to lift the grass and drop it across the flow of the gases. Evaporation of moisture (which, however, takes place more quickly from the leaves than from the stems) is so rapid that the temperature of the grass remains low. As soon as the grass particles reach a certain moisture-content, and before they attain a high temperature, they pass automatically from the tower and drum into cyclones. Leaf material leaves the hot-gas stream before stem. The second and third stages take place in revolving drums. As the grass passes through the drums longitudinally it comes into contact with transverse streams of hot gases. In succeeding stages the temperature is progressively reduced until, in the final one, it is similar to that of low-temperature dryers. Recirculation of drying gases may be employed in the second and third stages. At all stages the grass particles leave the hot gases as soon as they become dry enough and before they are scorched. High-temperature dryers are new to this country. They are said to have a higher efficiency than low-temperature types, but their operation requires greater skill and they are generally more expensive.

TRACTORS AND THEIR EQUIPMENT

Tractors occupy an important place on the farm as a source of power, and on many British farms they, together with motor trucks or trailers, have entirely displaced horses for farm work. An advantage of tractor power over horse is that the tractor can be used continuously for heavy work whenever soil and climatic conditions make the operations most effective. In addition to pulling implements like ploughs and cultivators, a tractor may be used with implements for bush and hedge clearing, ditch filling, and land levelling. Small tools for these purposes may be operated by farmers themselves, but the larger and more specialized, such as bulldozers and angledozers, which require powerful track-laying tractors, are usually in the hands of contractors. A tractor may be provided with a power-take-off to enable its engine to actuate the machine it is drawing. Thus a tractor can pull a binder and at the same time drive the binding mechanism. In this way the main wheel of the binder is relieved of the drive, wheel-slip on soft land is prevented, and the speed of cutting and binding is no longer dependent on the rate of forward travel. The power-take-off can also be used to work the knife of a mowing machine, the self-lift mechanism of a tool-bar, a winch, or some other drive. The winch may be mounted on the tractor or may be a separate trailed machine. Winches are extremely useful for manœuvring large machines—*e.g.* threshers—into awkward places, for pulling implements through patches of land on which the tractor wheels cannot get a grip, and for exerting a very heavy pull at a low travelling speed as is required with some drainage equipment. Most tractors are fitted with pulleys for belt work, and when properly governed they can be used to drive threshers, balers, etc.

Small "walking" tractors of from 1 to 10 horse-power, fitted with single- or twin-cylinder petrol engines, may be used for garden and orchard work. Most are provided with handles, like those of a plough, on which the controls are mounted and by which the machines are guided. They can be fitted with a plough body, cultivator tines, or other fittings to perform a variety of operations. The Ransomes tractor is a small track-layer driven from a seat, for which there is a range of miniature equipment including plough and tool-bar.

Tractors are generally started on petrol and thereafter run on vaporizing oil, but some take only petrol fuel and others are

fitted with compression ignition engines to run on diesel oil. Farm tractors may be divided into two groups: wheeled and track-laying. Wheeled tractors may be further subdivided into standard and row-crop types. The nominal horse-power attached to different makes is often misleading, but as a rule a machine of the lighter type, which develops about 10 horse-power at the draw-bar and 20 horse-power on the belt, can draw a two-furrow plough at fair speed on average land or a three-furrow plough on light land, and can drive the usual farm threshing gear. A 20 draw-bar horse-power outfit, dealing with four or five furrows, can plough 1 acre of medium land to a depth of 6 to 8 in. in one hour.

Most wheeled tractors are driven through their rear wheels only; a small number of four-wheel-drive tractors is in use. The former are moderate in price, and for ploughing on firm land they can be relied on to do very good work, but for secondary operations such as cultivating or drilling, the wheels tend to sink into the soil and cause unevenness. Again, when the land is soft, and particularly when it is heavy, there is a tendency for the wheels to slip; in a very bad case the machine may stick and dig itself in. Many designs of wheels and wheel treads have been tried, but there is some soft-bottomed land on which wheeled tractors of this type remain rather unsatisfactory, and there is a good deal of land where there is trouble if the load exceeds that of a two-furrow plough. Fitting half-tracks to a wheeled tractor, *i.e.* replacing the rear wheels by tracks, gives the tractor a draw-bar pull equal to that of a track-layer fitted with an engine of similar power. The half-track tractor, however, is not so manœuvrable as the track-layer.

For pushing on with operations in spring, for cleaning stubbles after harvest, and for ploughing many classes of land, two-wheel-drive tractors are usually quite satisfactory. When the engine of the tractor drives all four wheels the risk of slip is very largely eliminated; indeed the grip is almost as good as in the case of track-laying machines. A disadvantage of wheeled tractors is that the spade lugs that are needed on the wheels for soft land are damaging to roads, and it is necessary either to remove them or to fit road-bands over them before driving the tractors on the highway, and these alterations take time. Large low-pressure pneumatic tyres with special treads are now being used to overcome this difficulty. Their use is justified if there is much road work and if a good deal of time is spent drawing light implements.

They have the further advantage that they may effect a saving of fuel. On the other hand, pneumatics may have insufficient adhesion for certain heavy jobs; on juicy clover or any wet surface they may even be unable to transmit light power. The adhesion of pneumatic tyres is improved by keeping them at the lowest inflation pressure recommended by the manufacturers, by adding weight to the back axle, by using girdles or adjustable strakes, and by running in the highest gear possible. The back-axle-weight is increased either by attaching cast-iron blocks to the steel wheel centres, or by filling the tyres with water to which calcium chloride has been added to prevent freezing in cold weather. Girdles are similar to but much larger than the skid chains fitted to car and lorry tyres. Adjustable strakes are steel paddles or bars attached to the centre of the wheel in such a way that when they are required they can be extended to stand proud of the rubber tyres, and again retracted when not required.

Standard wheeled tractors are used for general farm work and do not have those special features associated with row-crop tractors. Row-crop tractors can be used for all ordinary purposes, but in addition they are specially designed for working in root and other row crops. They are given a high ground clearance so that they ride over growing plants and they are streamlined to give the driver an unobstructed view of the crop in front of him. In most makes the front wheels are set so close together that they straddle only one drill, and they are so pivoted that the tractor can turn in its own length. The rear wheels, which must be narrow-rimmed, are adjustable so that the track can be set for rows of different widths; and if the tractor has a wide front axle this too is adjustable. The rear wheels are equipped with independent brakes to facilitate turning on the headlands. The chassis of the machine is designed for the direct fitting of various tool-bars to carry implements such as ridgers, hoes, and cultivators, and a power-lift gear enables the implements to be raised out of the ground while the tractor is being turned on the headland. The power-lift may be mechanical or hydraulic. Most hydraulic lifts are used simply for raising and lowering the tool-bar, but the lift employed on the Ferguson system also regulates the depth of working.

Tool-bars are of three types: mounted on the rear of the tractor; underslung, *i.e.* underneath, between front and rear wheels; and forward, *i.e.* in front of the tractor. The rear tool-bar is usually better than the forward or underslung types for such operations as

ridging or cultivation of potatoes, where it would be a disadvantage to run over the work; but for the close side-hoeing of turnips the rear tool-bar is at a disadvantage because it is behind the driver, and because it swings over to the right if the tractor is steered to the left and *vice versa*, so that it may cut out some plants before the tractor straightens up again. Certain rear tool-bars can be converted into steerage hoes. The forward tool-bar is easiest to handle for splitting back potato ridges (see Plate XXIV, *A*), especially if it is fitted with diabolo-shaped rollers to run on the ridges. This is because all the tractor wheels are behind the covering-in bodies and therefore run in furrows, whereas with the other two types of tool-bar some or all of the tractor wheels have to be kept on top of ridges—a difficult operation, especially if the ridges are pointed or if the work is on a side-land. Another way of splitting is given on page 306.

For any row-crop operation on bare ground a marker is used to make a line on the soil down which the front tractor wheel is driven on the next bout. A convenient formula for setting a marker is as follows: if the front-wheel track is less than the distance between the outside cultivating units (*e.g.* ridging bodies or seeders) the distance of the marker from the outside unit is equal to the row width plus the distance between the front wheel and the outside unit. If the outside units are inside the front-wheel track the distance of the marker from the outside unit is the row width less the distance between the outside unit and the front wheel. It is sometimes difficult to drive the front wheel of a tricycle-type tractor down a mark. To overcome this difficulty "*sighting*" markers are fitted on to each side of the front of the tractor. These markers are treated as front wheels when setting the true markers, and in work are driven above the marks made by the true markers. Correctly set markers give accurate "joins" between successive bouts. (Markers can be set in the same way for a tractor pulling a corn drill.)

Track-laying tractors or crawlers have the great advantage that they take a powerful grip without exerting much pressure on the soil; indeed their pressure per square inch is much less than the treading of a horse. They can be used for heavy loads on almost any class of land. They are considerably more economical in fuel than are wheel machines, but their greater initial cost and their maintenance, particularly that of the tracks, may outweigh this advantage. The crawler is, however, the more efficient type

of tractor and, moreover, can go on the land earlier after rain and so can work a greater number of days per year.

The cost of running a tractor is almost as high when it is running light as when it is fully loaded. When the machine is used to its full capacity it can perform operations at a lower cost than can horses, but it is wasteful to use it for jobs that make no great demand upon its power. Moreover, unless there is automatic control of the cooling, under-loading makes for cold running with consequent oil dilution and excessive cylinder wear. It is rarely possible to offset the disadvantage of a light load by running the tractor at a high speed. Many farm operations with existing implements have to be done at speeds not greatly in excess of that of a walking horse, and therefore to take advantage of a tractor special large implements should be employed or, alternatively, the load should be made up by hitching implements in tandem. A set of harrows, for instance, can often be hitched to a tractor corn drill. When this is done, and the drill is being run "wheel to wheel," the harrows should be hitched in such a way that they swing from one side of the drill to the other when turning on the headland and do not obliterate the outside wheel-mark as the outfit goes across the field. If the corn drill has a marker, the harrows can cover the full width of the drill. Harrows can also be hitched behind a set of tandem disc harrows. Instead of hitching two different types of implements in tandem, two or three identical implements, such as three corn drills or three manure distributors, are often used in echelon behind a single tractor. Where three are used it is usual for the central implement to be hitched ahead of the two lateral ones. Most row-crop cultivations do not impose a heavy draft, and they can be performed most economically by machines of relatively low power.

When horses are kept to do all the farm work their number must be sufficient to meet demands at peak seasons, so that during the rest of the year they are not fully employed but cost little less to keep. In such a case it is a great saving to reduce the horses to the number that can be fully employed almost all the year round, and to meet the seasonal demand for extra labour by providing a reserve tractor.

CARTS AND TRAILERS

Carts were first made by village craftsmen to suit local conditions, including the steepness of the hills, and consequently

there is considerable variation in the types used in different parts of the country.

The two-wheeled tipping cart is very popular, and by the use of extra fittings can be adapted for almost every farm purpose. For heavy materials it is used without wings or topside boards, for more bulky stuff it may be used with either small or big wings and for hay or harvest work it can be fitted with hay ladders or frames. Although designed for one horse, a second can be yoked in tandem. The tail board is, of course, removable and the body can be tipped independently of the shafts and in some makes the body can be locked in a semi-tipped position to facilitate the heaping of dung, the scattering of roots on grassland, and other jobs of that sort.

The fitting of pneumatic tyres to farm carts is a great improvement which reduces the draught by as much as 40 per cent. Old carts can be fitted with the new wheel equipment, but owing to the new axles being lower than the old a certain amount of blocking up is required. When carts are designed to suit the new wheels a lower floor level can be secured, and the capacity of the body may be increased to take advantage of the reduced draught.

A long, low sort of farm cart is made to suit pneumatic tyres. With a body about 9 ft. long, a floor less than 3 ft. from the ground, and sides no more than 11 in. high, it is very easy to load; but it does not tip to such a steep angle as the older sort of box cart and therefore makes a less compact heap. Its capacity can be increased for hay or corn harvest by the addition of side wings.

In some districts long, open-framed corn carts are kept in addition to a full complement of box carts. The corn carts are very handy for harvest, for taking in stacks of hay or crops for threshing, or for shifting bulky materials such as sheep nets. Their inclusion in the farm equipment saves the time required to convert general-purpose carts for bulky material.

Wagons are used for agricultural purposes in southern areas. They are generally large and heavily made, with big diameter wheels behind and small wheels in front which turn beneath the body. They have shafts for one horse, and one or two extra horses may be yoked in tandem. A wagon has a much heavier draught than a cart, but has the advantage that its load does not require to be balanced; it is most usefully employed for carting very heavy, awkwardly shaped, or bulky materials.

In some parts of the country low horse-drawn bogies are

employed in sets of two or three for moving ricks of hay from the field to the stack. They are fitted with winding gear which enables the ricks to be pulled straight on to their platforms.

Pneumatic-tyred tractors are very useful for haulage work, especially those that are fitted with a high gear enabling them to attain a road speed of perhaps 15 miles an hour. Two-wheeled tractor-trailers, with or without tipping equipment and high sides, are turned out by various makers. They are usually made front-heavy so that part of the weight of the load is thrown on to the tractor draw-bar. This might give rise to hitching difficulties if it were not for the fact that a jack or a small castor wheel, adjustable for height, is incorporated in the draw-bar. When the tractor is unhitched from a loaded trailer the jack or wheel is let down so that it takes the weight off the tractor, and the trailer draw-bar is then at the correct height for coupling-up again. Also, because the trailer is front-heavy, tipping is done mechanically either by a hand-operated tipping gear similar to that used on lorries or, on those trailers equipped with the necessary telescopic draw-bar, by withdrawing a pin from the draw-bar and reversing the tractor. There are trailers with hydraulic tipping mechanisms worked off the power-lift of the tractor. Some trailers are made to tip sideways and are very useful for carting potatoes to the clamp.

Trailers may be used to convey all kinds of heavy produce. They may also be employed for harvesting, root carting, etc., but for this class of work a single trailer is not always economical, for it requires a set of two or three to keep a loading squad fully employed.

For corn harvest the tractor is sometimes used for transporting the loads from the field to the stack, while horses are used to pick up the loads. A two-wheeled forecarriage, with shafts, is fitted to the trailer draw-bar to make the trailer suitable for horse work. Some progress has been made in designing tracks for heavy trailers to enable them to deal better with heavy loads on soft land. Low-loading trailers equipped with skids and hand-operated winches are used for transporting implements including steel-wheeled and track-laying tractors. Such are equipped with pneumatic tyres which, on the largest trailers, can carry loads up to 10 tons. A fuel trailer is useful when a tractor is working a long distance from the farm buildings. It may have a 120 to 200 gal. fuel tank, a semi-rotary pump to put the fuel into the

tractor, a lock-up box in which oil, grease, and spares (such as ploughshares) can be kept, and sometimes a platform on which the tractor driver can put his bicycle or motor cycle when moving from one field to another.

The Opperman Motocart (Plate XXIV, *B*) is a self-propelled three-wheeled vehicle suitable for light farm transport. The air-cooled engine is built into the centre of the large front wheel by which the vehicle is steered.

Many farmers now keep one or more motor trucks for road haulage and for some jobs on the farm. Such vehicles may be used as lorries or may be fitted with the usual drop sides and tail-board to take bulky produce; they may be provided with high sides for transporting cattle or with double decks to provide maximum accommodation for sheep; they may also be fitted as horse-boxes. Light trailers, strong enough to carry one horse or one beast, are frequently used behind high-power motor cars.

PART II

CROPS

CHAPTER I

CROP VARIETIES AND PLANT BREEDING

THE Principles of Genetics are outlined in Chapter I of Part III. Meantime it is necessary to an understanding of some aspects of crop husbandry to explain what varieties are, what steps are necessary in particular cases to maintain the purity and health of stocks, and how new varieties are produced.

The term *variety* connotes a group of plants that are more nearly alike than those that make up a species or sub-species; but in some cases the individual plants belonging to a particular variety differ, in genetic make-up, in varying degree. Four main types may be distinguished, *viz. clones*, *pure lines*, *strains*, and *hybrids*.

1. Where simple vegetative propagation is the method used in the production of the commercial crop—*e.g.* as in the potato, strawberry, or blackcurrant—the so-called variety is a *clone*, *i.e.* it consists of a group obtained by vegetative division and redivision of a single original parent plant. Genetic variations —mutations or " sports "—may indeed occur from time to time; for instance, a white variety of potato may occasionally produce a red or russet tuber, and the variant can be multiplied to provide a new variety. In some species, too, abnormal behaviour of the chromosomes may result in the production of " off types "; for example, some varieties of potato produce a proportion of " bolters " or " wildings " or both, and it is essential to the maintenance of the stock that these be eliminated. Again, whereas only a few virus infections are transmitted by the parent to offspring through the true seed, these can be, and often are, transmitted in vegetative propagation. Thus a potato plant infected with leaf roll during the early part of the growing season will pass on the virus to its progeny. Moreover, the infection may be spread from plant to plant in the field either by contact

or through the agency of leaf-sucking insects. Hence in the production of seed potatoes it is necessary to remove (*a*) plants of any different variety, commonly called " rogues "; (*b*) bolters and wildings; and (*c*) plants showing symptoms of virus infection.

Many plants can be vegetatively reproduced by cuttings, layers, pieces of rhizome, etc. But in some cases a cutting produces only a feeble root system. This is true of most kinds of top fruit, and it has long been the practice to graft or bud the scion of the desired variety on to a seedling rootstock of the same or a related species. Thus cultivated varieties of apple were at one time commonly grafted on seedling crab stocks. But the growth habit of the scion is influenced by the rootstock, and seedling crabs show a wide range of variation. It is therefore preferable, where possible, to propagate both stock and scion vegetatively and, in the case of the apple, certain particular types produce stool-shoots that root freely. Thus a particular variety, such as Cox's Orange or Bramley's Seedling, budded on Malling IX stock, gives a tree that can be relied upon to grow only to a small size and to come into bearing at a young age.

As already said, new types—vegetative " sports "—occasionally appear in clonal varieties, but these are rare and very seldom of any economic value. New varieties are obtained by raising seedlings, generally produced by hybridization. Since most clones are highly heterozygous, a wide range of material is produced even when the parent plant has been self-pollinated, but the chances of useful forms are much greater among seedlings that have been produced by cross-fertilization. If a promising type appears among a group of seedlings, this is multiplied vegetatively and the resultant clone is compared with established commercial varieties. Since the characteristics of the new clone will be transmitted to its vegetative offspring, there is no need to " fix the type " by selection.

The newer techniques for producing polyploid forms, and for making inter-species or other " wide " crosses, are described later.

2. Many of our annual crop plants—for instance, wheat, barley, and oats (but not rye)—are habitually self-fertilizing. Repeated reproduction from self-fertilized plants has the effect of " fixing " the plant's heredity—*i.e.* of eliminating genetic variability. Hence a pure-line variety—*e.g.* of wheat—reproduces

its characteristics just about as regularly and fully as a clone—*i.e.* it produces only occasional "sports." It also may occasionally produce "off-types" due to some abnormal chromosome behaviour; the best-known instance is the "fatuoid" type of oat (so-called because it bears some resemblance to the wild oat) which originates through the loss of a particular part of one of the chromosomes.

In the multiplication of pure-line varieties for the supply of commercial seed no special precautions are ordinarily necessary to obviate the risk of cross-pollination. Certification schemes are based on the authenticity (trueness to name) of the growing crop, on its purity, and its freedom from weeds, especially those whose seeds would be difficult to remove by the available seed-dressing machines.

New pure-line varieties are produced by artificial cross-pollination in the hope of getting, among the hybrids, forms possessing better combinations of desirable qualities; for instance, a wheat with stout straw and high yield potential, but low-quality grain and high susceptibility to a particular strain of rust, might be crossed with another resistant to the rust, of high-quality grain, but with weak straw and relatively low yielding capacity. In certain cases difficulties arise out of the different chromosomal structure of the types that might otherwise be selected; for example, the "bread" wheats have forty-two chromosomes and the Rivet types only twenty-eight, and the hybrid plants, if they can be produced at all, will ordinarily be sterile. Such difficulties, however, can be overcome in some cases.

3. Next we have a group of plants that are habitually cross-pollinated and which, if restricted to self-pollination, produce little seed and yield progeny that show a marked loss of vigour as compared with the parent, the deterioration being comparable to that which commonly occurs when a strain of animals is closely in-bred. To this group belong all the brassicas, beets and mangolds, rye, and all the common grasses and clovers. Some, including the grasses and rye, are wind-pollinated, while the clovers are entirely dependent on insects. A variety (*strain*) of any of these is, genetically, rather like a breed of animals—*i.e.* the individual plants are rather highly heterozygous, and there is considerable genetic variation as between individuals. Hence continuous selection is required to maintain a reasonable degree of "trueness to type" and to maintain the desired qualities.

The normal procedure in producing commercial seed of a strain is to select individually a number of plants of the desired type and to grow these, as a group, at a sufficient distance from any extraneous source of pollen. Since the produce from these selected plants—" mother " or " stock " seed—would be too expensive for the farmer's use, the strain is " grown on " for one or more generations, without selection, to yield commercial seed.

Seed-inspection schemes for the crops of this group are based firstly on the suitability of the site on which the commercial seed is to be produced; for instance, seed-crops of sugar-beet must not be grown in close proximity to those of mangolds, fodder beet, or red beet, and the more important seed-growing areas have therefore been divided into zones for this group—one zone growing only sugar-beet, another only red beet, etc. Again, for instance, the proposed site for certified S.143 cocksfoot must be examined in relation to the possibility of cross-pollination from plants in adjacent hay fields, pastures, or hedgerows; and a field of pasture to be harvested for wild white clover seed must not be adjacent to another containing Dutch white clover. In each case the growing crop must be inspected for trueness to type and for the absence of weeds, especially those whose seeds would be difficult to separate from the sample.

New strains of grasses, roots, etc., are built up by careful selection of parent plants continued over a number of generations.

4. A further group of plants, while habitually cross-pollinating and suffering a greater or lesser decline in vigour when subjected to continuous selfing, yet can survive when reduced to the condition of pure lines. In the process of continued selfing numbers of the least desirable hereditary factors (genes) are eliminated. When two such in-bred lines are crossed there is an increase in vigour, so marked that the hybrid may be substantially better than the original out-bred strain. The system of breeding suggested by these facts is closely similar to that used in the production of commercial meat animals; for instance, Cheviot ewes may be mated with Border Leicester rams to produce half-breds, and the process may be carried a stage further by mating the half-bred ewes to a Suffolk ram.

The most notable success achieved by this procedure has been with maize. The maize plant bears male and female inflorescences separately on the same plant, so that if two lines are grown in

alternate rows and the male flowers (tassels) are removed from the one, the detasselled plants will be pollinated exclusively by the other. The process may be carried a stage further—to a "three-way" or "four-way" cross, *i.e.* if A, B, C, and D are four in-bred lines, commercial seed might be A(B×C) or (A×B) (C×D). In the United States, hybrid varieties so produced have, on average, outyielded the old open-pollinated varieties by some 20 per cent.

The principle involved in the production of hybrid maize is obviously difficult to apply in practice to the general run of crop plants. Hybrid tomato seed is produced commercially, the cross-pollination being effected by hand. Hybrid onion seed can also be produced by selecting as the female parent a male-sterile clone—*i.e.* a type that can be reproduced vegetatively by bulbils. It has also been suggested that hybrid varieties of grasses might be produced by growing side by side two strains both of which were nearly, but not quite, self-sterile; the two parent types could thus be reproduced and maintained separately, and be grown in alternate rows for the production of hybrid seed.

The production of new hybrid varieties involves a long-continued process of self-pollination, some ten generations of selfing being commonly required to obtain a pure line—*i.e.* a completely homozygous group. A number of in-bred lines having been produced, the numerous possible combinations (two-way, three-way, and four-way crosses) must be made and tested for their commercial usefulness, the various pure lines being maintained permanently.

Polyploids.—Most wild species of plants have a characteristic chromosome number, and it happens that certain cultivated crops—*e.g.* barley—have the same number as the wild plants from which they have been derived. In other cases the cultivated form has twice or three times the number characteristic of its wild ancestors. Thus, in the wild wheat-grasses the basic chromosome number is seven, *i.e.* the generative nuclei of the pollen grain and the ovum each contains seven chromosomes, and the vegetative cells fourteen. Seven is the *haploid* and fourteen the *diploid* number. But many cultivated crops are polyploids—*i.e.* their chromosome number is two or three times that of their wild progenitors. Thus Rivett wheats are *tetraploids* (twenty-eight chromosomes) and the common bread-wheats *hexaploids* (forty-two).

The doubling of chromosome numbers can be achieved by

artificial treatment of the hybrid material, notably by the use of the drug Colchicine. One type of polyploid (*autopolyploid*) is produced by the doubling of the chromosome number without hybridization. In certain cases autopolyploids have proved to be potential improvements on the diploid parent. Thus polyploid sugar-beets, which are already widely grown in certain Continental countries, give, upon average, higher yields than the ordinary types.

The main application of the technique is, however, in the making of " wide " crosses—for instance, between two distinct species. Thus rye (fourteen chromosomes) can be crossed with wheat (forty-two chromosomes), but the hybrids (twenty-eight chromosomes) are ordinarily sterile. By inducing polyploidy, a hybrid (with fifty-six chromosomes) can be obtained that shows normal fertility. The technique is being used in various species. In potato breeding, for example, the hope is to introduce, from certain wild species, immunity to potato blight and other diseases.

Variety Testing.—It is obviously desirable that new varieties should be subjected to field trials, under the varying combinations of soil and climatic conditions that occur in the area where the crop is grown. The general procedure is to grow a new sort in small observation plots for a year or two in order to form a preliminary judgment. If the variety appears to show promise it is then included in trials, carried out at a number of selected localities, each representative of a particular agricultural region. A well-established old variety is used as a control. Three years' tests must commonly be awaited before the new variety can be placed on the " approved " list.

It will be obvious that such a system will give valuable information about clonal, pure-line, and hybrid varieties, since these, with precautions against admixture and virus infection, can be relied upon to breed true to type. The problem is more difficult in the case of strain varieties—grasses, roots, brassicas, etc.—because the average type of a particular strain may change either by reason of the amount of care that is exercised in selection of the mother plants or according to the individual selector's conception of the ideal type. In such cases trials must be repeated at relatively short intervals and must, in certain cases, include material offered under the same name by different seedsmen.

CHAPTER II

THE CEREALS

WHEAT

THE cultivation of wheat was begun in prehistoric times and the cereal was greatly valued by the ancient Persians, Greeks, and Egyptians. Cultivated wheats seem to have originated by the accidental hybridization of certain species of wild grasses, and the varieties now grown have been evolved by the selection of subsequent mutations and by hybridization, either accidental or artificial. Wheat was introduced to Britain by Neolithic settlers about 2400 B.C.

Wheat, since it is the favourite cereal for the production of bread, is the basic carbohydrate food of Western peoples. In Asia, on the other hand, the main food grains are rice and various millets. Wheat grain is frequently fed as such to poultry. Otherwise it is ground to flour, the milling by-products being fed to farm animals. Each grain of wheat consists of an embryo plant in close contact with an ample store of starchy and nitrogenous food material, the whole being surrounded by a pericarp or coat, which goes to form the miller's bran. Flour consists of the most digestible portion of the food store, and is obtained by subjecting the grains to a milling process. The admirable qualities of wheaten flour depend largely upon the nature of the nitrogenous portion, which is in the form of gluten. When the flour is prepared for the baking process some of the starch is converted into sugar, which in turn is broken up by the action of the yeast, with the formation of carbon dioxide gas, whereby the dough is puffed up into a spongy mass. The so-called " strong " wheats have a high gluten-content, and the dough produced is of a tough, rubbery nature that prevents the escape of gas and produces a light, well-risen, even-textured loaf. The diastatic power of wheat, *i.e.* its capacity for producing sugar, is also important, and sometimes bakers have to blend malt extract with flour of poor diastatic quality. Other things being equal, the best flour from the baker's point of view is the one that yields the largest number of loaves per sack.

Milling of Wheat.—Before milling takes place the wheats are blended, so that the flour produced will be of the desired strength for baking purposes. In modern flour-milling the wheat is first of all subjected to a very thorough cleaning process. Not only does this remove weed seeds and foreign matter that would injure the quality of the flour, but also gets rid of stones, pieces of iron, and scraps of material that would be likely to injure the delicate machinery used in the milling process. The milling proper is done by passing the grain between a series of rollers of increasing fineness and closeness of setting, so that the berries are cracked and the endosperm or floury portion is liberated with the least possible breaking up of the dark-coloured bran. At each stage the material issuing from the rollers is sorted out, by means of sifting machines and fans, into materials of different grades and degrees of fineness. When home-grown wheat is milled for flour of "pre-war" standard, about 68 per cent. of the grain is recovered as flour, but the best imported wheats, subjected to the same process, yield up to 74 per cent. flour. The final products of the milling process are: (1) Flours and semolinas of different grades; (2) wheat germs; (3) middlings, sharps, thirds, pollards, or weatings, which may or may not be separated into "fine" and "coarse" grades; and (4) bran, which again may be separated into "broad" and "medium." Higher rates of extraction, such as 80 or 85 per cent., give rise to flours of a lighter or darker shade of greyish-brown. These, owing to the inclusion of part of the germ and more of the aleurone layer, have a much better vitamin content (vitamin B) than the ordinary white flour. When the rate of extraction is raised above 85 per cent. the flour necessarily contains more of the fibrous outer layer of the grain, and is therefore less digestible. Methods of milling devised during the war, and based on analysis of the various parts of the wheat berry, aimed at retaining the vitamins as far as possible while eliminating as much as possible of the bran. It is possible by these methods to get a flour which is almost white and which yet contains practically all the valuable nutrients of the grain, the extraction rate being about 83 per cent. In many countries a flour of wheat and rye is the standard material for baking. In case of shortage a proportion of barley or maize may be added, but bread made from such blends is generally less palatable than that produced from wheat alone.

Quality of Wheat.—Wheat is valued according to its

suitability for milling purposes. A good milling wheat should yield the largest possible proportion of flour and a correspondingly small proportion of milling offals ; this quality is indicated by the thinness of the bran and the largeness of the wheat grains, large grains having a relatively smaller surface than small grains, and consequently a smaller proportion of bran. It is essential that the wheat should be in a sound condition, free from odours and indications of heating ; it should also contain a minimum of weed and other foreign seeds. The wheat should be hard, as hardness indicates the presence of a minimum proportion of water.

Wheats of good quality for bread-making have a horny or flinty appearance and an absence of flouriness when the grain is examined in cross-section, and they possess a high protein-content. Yet the converse is not true, as wheat may have a hard translucent endosperm and yet not be "strong." "Weak" wheats are usually soft, starchy, and opaque ; but a weak wheat can be given a "strong" look by nitrogenous manuring and early cutting. Actually the rapid ripening that takes place in dry, hot countries favours the development of strong wheat, whereas in this country the moist atmosphere and slow ripening are conducive to the development of soft grain. While some wheats may require favourable conditions to produce grain of good baking quality, the fact that strength can be inherited independently of everything else means that the choice of the variety is the most important factor in the production of strong flour. It should be noted that whereas "strength" is required in wheat for bread-making, "weak" wheats give the class of flour required for most sorts of biscuits and many kinds of cakes. Other varieties that are not particularly good either for bread or biscuit-making find, when supplies are abundant, a ready market as poultry food.

If wheat is being bought for seed purposes it should be plump, with a smooth, well-filled skin, and show every indication of having attained perfect maturity at harvesting ; it should bear no signs of weathering, overdrying or heating in the stack, should be free from bunt, and should be as free as possible from weed seeds, a condition of much greater importance in seed wheat than in a sample for milling. The seed should have a high germinating capacity, and in case of doubt an official test should be procured. The Seeds Act requires that all wheat sold as seed should give a germination of at least 90 per cent.

The best wheat from the farmer's point of view is not necessarily that of the highest baking quality. In a free market, of course, the higher prices will ordinarily be obtained for samples of better baking quality. But much British wheat is used for biscuit manufacture; moreover, in the production of baking flour it is usual to blend the "weaker" home-produced types with "strong" imported grain. Yield of straw may be important—*e.g.* to the potato grower or the dairy farmer; otherwise the shorter-strawed varieties are commonly preferred on account of their adaptation to modern harvesting methods. The individual farmer should choose varieties suited to the soil and climatic conditions of his farm and resistant to the diseases locally prevalent. On rich or highly manured land resistance to lodging is of obvious importance.

Varieties of Wheat.—Wheat, in common with many other species of cereals, is practically always self-fertilized. Under ordinary conditions each sort breeds true, and strains developed from individual plants, selected for their apparent merit, are ordinarily the same as the produce from unselected parents. How, then, have the dozens of varieties of wheat come into existence? Some, no doubt, have been developed from rare cases of mutation or of cross-fertilization under natural conditions. The great majority of our wheats, however, have been produced by artificial cross-fertilization of pre-existing distinct varieties, with selection from among the diverse types that appear in the progeny.

The testing of varieties of wheat, and of many other crops, is carried out in England and Wales by the National Institute of Agricultural Botany and the National Agricultural Advisory Service; in Scotland by the Department and Colleges of Agriculture and in Northern Ireland by the Ministry of Agriculture.

The list of recommended varieties, as at the time of writing, is given later (pp. 258-261); but many of those mentioned may probably be displaced by others in the course of a very few years. The varieties included in the list as it stands may, however, serve to illustrate the principles upon which a selection, for any given set of circumstances, should be made.

The first and most important criterion is yielding capacity. In this respect it is broadly true that the modern French types out-yield the English "quality" varieties as well as the Dutch white types and those of the Scandinavian group.

The French wheats are characterized by a thick-walled (or in some cases solid) straw. The other groups have generally thin-walled straw. Again, in the typical French varieties the straw is short or very short, and strong. In general, thick-walled and short straw, when they go together, make for high resistance to lodging, which is of prime importance under conditions of high fertility.

As regards the quality of the grain, it has already been indicated that " hardness " is important in relation to the baking of bread, whereas for most sorts of biscuits a " soft " grain is preferred. There are only five varieties on the recommended list which can be described as hard. A further number—Squarehead's Master, Little Joss, and the white varieties Juliana, Wilhelmina, Staring, and Victor—have the quality required for biscuit flour.

The typical French wheats are poor from either point of view and hence must be blended, for the production of commercial flour, with imported wheats possessing more than the required degree of strength for baking.

A further characteristic is the degree of liability to sprouting during wet harvests. This is specially important in the wetter districts. Where harvesting is by "combine," liability to " shattering "—*i.e.* the shedding of grain from the ripe ear—is a serious defect. Holdfast is specially prone to sprout and Bersée is very liable to shatter. It is a curious fact that the tendency to sprouting is correlated with grain colour, white varieties being more prone than red.

Susceptibility to disease is of obvious importance. Some of the French types, for example Hybrid 46 and Vilmorin 27, are rather highly susceptible to loose smut; some others—Nord Desprez and Capelle—while resistant to loose smut, are susceptible to yellow rust. Loose smut (see p. 271) spreads by spores, and the incidence of the disease may increase in a particular stock until this has to be discarded. Yellow rust tends to be most serious under conditions of high fertility. There appears to be little or no difference, as between varieties, in susceptibility to the soil-born diseases (Take-all, Eyespot, or the Brown Foot-rots). It has, however, been shown that Eyespot infection causes more lodging in the long-strawed than in the short-strawed type.

Winter hardiness is of obvious importance in the winter varieties. This, however, is not a simple matter of frost resistance, for certain Swedish varieties, that are highly frost-hardy, suffer

severely under typical British winter conditions—*i.e.* wet soil with alternating frost and thaw.

The better varieties available at the time of writing, arranged according to type, were as follows :—

Winter Wheats of High Milling Quality.—*Holdfast.*—Yeoman × White Fife (Plant Breeding Institute, Cambridge). White chaff and white grain of high milling and exceptionally high baking quality. Should only be used on soils of medium and heavy physical texture in a high state of fertility, and under these conditions it has a wide range of adaptability. The grain is liable to sprout in a wet harvest.

Redman.—Yeoman × Squarehead's Master (Gartons Ltd., Warrington). Red chaff and red grain. A variety with moderately short straw, suitable for fairly fertile soils, and producing grain of good milling and baking quality.

Warden.—Benefactress × Yeoman (Gartons Ltd., Warrington). White chaff and white grain. A variety with moderately short straw suited to fairly fertile soils. The grain is of good milling and baking quality.

Yeoman.—Red Fife × Browick (Plant Breeding Institute, Cambridge). White chaff and red grain of high milling and baking quality. The straw is of medium length. Yeoman is at its best on highly fertile soils, or when manured intensively.

Winter Wheats particularly suited for Biscuit-making.—*Victor.*—(Squarehead × Red King) × Talavera (Gartons Ltd., Warrington).

Wilhelmina.—(Squarehead × Zealand White) × Squarehead (Plant Breeding Institute, Wageningen, Holland).

These are very similar varieties with white chaff and white grain. The ears are dense and the straw of medium length. Suitable for soils of medium fertility.

Juliana.—Wilhelmina × Essex Smooth Chaff (Plant Breeding Institute, Wageningen, Holland). White chaff and white grain. A variety with dense ears and straw of medium length. Rather late maturing. It is suitable for soils of medium fertility. Juliana is moderately susceptible to loose smut.

Little Joss.—Squarehead's Master × Ghirka (Plant Breeding Institute, Cambridge). Red chaff and red grain. Ears long and lax. Straw long, leafy, and very liable to lodge except under conditions of low fertility. Resistant to yellow rust, but moderately susceptible to loose smut.

Steadfast.—Little Joss × Victor (Plant Breeding Institute, Cambridge). Red chaff and white grain. Straw not quite so long as Little Joss and stronger, and, like Little Joss, resistant to yellow rust. Steadfast can be used on rather more fertile soils than Little Joss.

Squarehead's Master.—Red chaff and red grain. One of the older varieties still grown because of its reliable behaviour in many districts. The straw is medium to long and rather liable to lodge. No. 13/4 (selected by Plant Breeding Institute, Cambridge) has proved to be a high-yielding strain of this old "land" variety.

Squarehead II.—Squarehead's Master × Yeoman (C. W. Marsters Ltd., King's Lynn). A wheat of the Squarehead's Master type, but possessing shorter and better standing straw.

Winter Wheats, Other Varieties.—*Jubilégem.*—Vilmorin 23 × Iron III (State Plant Breeding Institution, Gembloux, Belgium). White chaff and red grain. The straw is short and stiff, and it is a good yielding variety suitable for rich soil. It is rather susceptible to mildew and to yellow rust.

Bersée.—Hybride des Allies × Vilmorin 23 (Monsieur Blondeau, France). White chaff and red grain. An early maturing variety with medium-length straw which gives good yields of grain under a wide range of conditions. However, the straw is not strong enough for highly fertile land, and the ear tends to shatter when over-ripe. Bersée is an "alternative" variety which can be sown in the spring if necessary.

Rivet.—A bearded variety with grey-brown hairy chaff and red grain. The straw is long, but stands moderately well. In trials of Rivets the highest yield and the best standing straw was produced by Rampton Rivet (selected by Plant Breeding Institute, Cambridge).

Vilmorin 27.—(Dattel × Japhet Parsel) × (Hatif Inversable × Bon Fermier) (Vilmorin, Andrieux, France). White chaff and red grain. A short stiff-straw variety giving heavy yields on rich soils, but very susceptible to loose smut.

Hybrid 46.—Benoist 40 × other hybrids (C. W. Marsters Ltd., King's Lynn). White chaff and red grain. A heavy-yielding, short, stiff-straw variety suitable for growing under highly fertile conditions. Very susceptible to loose smut. (May replace Vilmorin 27.)

Pilot.—Little Tich × Swedish Iron (Gartons Ltd., Warrington). White chaff and red grain. A late maturing variety with straw of

medium length and standing power, suited to soils of medium fertility. The grain behaves as a "hard" wheat in milling. Rather susceptible to yellow rust.

Staring.—Vilmorin 23 × Juliana (Central Bureau, Rotterdam, Holland). White chaff and white grain. A rather late maturing variety with medium to short straw. It is suitable for soils of medium fertility. It is slightly higher yielding than Juliana and not so susceptible to loose smut. (May replace Juliana, Wilhelmina, and Victor.)

Cappelle Desprez. — Hybride du Joncquois (Desprez 80) × Vilmorin 27 (Monsieur Desprez, France). White chaff and red grain. A heavy-yielding, short, stiff-strawed variety, suitable for growing under highly fertile conditions. Slightly susceptible to yellow rust. (May replace Jubilégem.)[1]

Spring Varieties.—True winter wheats sown in the spring may fail to come into ear in the year of sowing—*i.e.* they require a period of low temperature after germination to induce ear formation. Spring wheats do not require exposure to low temperature, and hence may be sown as late as about the middle of April. But certain varieties which, by this definition, are included in the spring group are highly winter-hardy. The best known examples are *Bersée* and *Atle*.

Varieties for Late Winter (January till Mid-February) Sowing.—Most of the earlier-ripening varieties of winter wheat, given reasonably good field conditions, can be sown at the time indicated with good hope of success.

Varieties for Mid-February to End-of-March Sowings.—*Atle*.—In widely spread trials this Swedish variety has consistently yielded well. It ripens early, and its stiff short straw makes it particularly useful for rich soils or where the crop is undersown with "seeds." The chaff is white, and the grain small, red, and of high milling and baking quality.

Bersée.—Although often used as a winter wheat, this may be sown with safety as late as March. It has white chaff and red grain. The fairly short straw stands well, and the yield is good.

Varieties for April Sowing.—The sowing of wheat after March is rarely advisable except on very fertile soils, since otherwise barley is more reliable and will ordinarily yield a heavier crop.

[1] Warden, Wilhelmina, Steadfast, Squarehead II and Vilmorin 27 were withdrawn from the Recommended List for 1954.

Fylgia has tapering ears of medium size, red chaff, and red grain of good quality. It ripens early, and its rather short straw stands fairly well.

Atle is suitable for sowing at this period only on highly fertile soils.

THE CULTIVATION OF WHEAT

Soil and Climate.—Wheat thrives in subtropical, warm temperate, and cool temperate regions. It is grown in this country as far north as Ross-shire, and is cultivated more or less extensively in all the eastern and midland counties. The western counties and districts of heavy rainfall are less suitable for wheat, because the crop requires to be grown in an early district if it is to ripen properly and because the yield is very dependent on summer sunshine. Wheat is extremely deep rooted and drought resisting, and on all except very light soils gives the best yields in dry and sunny seasons; it is also more resistant to winter frost than either barley or oats. In Britain it is traditionally a winter crop, but the introduction of new spring varieties, notably Atle and Bersée, has resulted in a rapid expansion of spring sowings.

The more "body" there is in a soil the more suitable it is for the growth of wheat; consequently this cereal is found attaining perfection on heavy loams and clays. Satisfactory crops can be grown on light land in good condition, but if the land is light and also poor, wheat is likely to be a failure; indeed it is a rule that this cereal requires the land to be in good heart. On light soils the yield is often only moderate, but the quality of the grain is not inferior; when grown on peaty soils the quality is usually poor, while the vegetation is luxuriant and the yield of straw very large. It is the safest cereal to grow on really rich land, as it stands heavy manuring, and, if a strong-strawed variety has been selected, is not very liable to lodge.

Place in Rotation.—In districts where bare or bastard fallowing is practised, wheat is most commonly taken after the fallow. This practice allows very early sowing of the crop, although little is now sown before late September. During the fallowing operations, which are conducted at a time of the year when the temperature is high and the soil organisms are particularly active, the continual aeration, mixing, and stirring of the soil allow the organic matter to decompose rapidly with the ultimate production of nitrates. As the nitrates are not held in

the soil but are carried away in the drainage water, it is advisable to sow a crop in the autumn which will be able to intercept and absorb these nutrients before they can be washed away by the winter rains. The wheat crop is admirably suited for this purpose. In most cases reasonably early sowing is an advantage, allowing the plants to become well established before the advent of winter so that they suffer little from the ill-effects of frost and thaw. On the other hand, if wheat is sown too early and becomes "winter proud," it is liable to lodge and produce a poor crop.

Since bare fallowing is no longer widely practised, the wheat crop frequently follows "seeds," the decomposition of the turf liberating nitrogen throughout the spring. It may also, with advantage, follow potatoes, as then the soil contains a considerable residue of the heavy manuring usually applied to that crop. There is, however, no hard-and-fast rule, and wheat is frequently sown after leguminous crops, such as peas or beans, or after roots that have been carted or fed off early in the season. Wheat seldom follows another cereal except where the risk of wheat bulb-fly attack precludes the normal succession (see p. 274). The growing of wheat after wheat or barley commonly leads to a build up of soil-borne disease (see p. 272).

Preparation and Sowing.—The quantity of seed required to sow an acre will vary according to a number of circumstances. Some varieties of wheat have much larger grains than others, and if the same number of plants is required per acre in all cases, it is obvious that the large-grained varieties must be seeded at a heavier rate. With this as with other species, for a given variety, the larger the seed the better the growth of the plants at the outset.

The rate of seeding must also be varied according to the time of sowing. A field which, when sown in September at the rate of 2 bushels ($1\frac{1}{8}$ cwt.) per acre, will produce a perfectly satisfactory crop, would, in all probability, produce an inferior crop if seeded at that rate in November, although a seeding at the rate of 3 bushels per acre at the latter date would give a normal yield. Early sown wheat, then, which has time to develop a strong growth in the latter end of the growing season, and will spread considerably before winter sets in, can be given a thinner seeding; if put in very late in autumn or early in spring, when conditions are severe, more seed must be used. The best time for seeding depends a good deal on the fertility of the soil, for early sowing on rich

land causes the crop to become winter proud. Local experience will serve as a guide, but early October is usually the optimum time on poor land, while November (or in extreme cases December) is best on good land that is in high condition. If on poor land the crop cannot be planted early, it may be best to defer seeding until February or early March.

The optimum seeding depends, too, on climatic and on soil conditions. In the northern and upland districts more seed is required than in the more genial southern counties. Good soil, because of its capability of producing active growth during the seedling stage, requires a thinner seeding than poor, where the plants are incapable of doing more than existing during the winter months. Normal seed rates for standard varieties sown in average soil by drill in October may be put at 2¼ bushels (1¼ cwt.) in the southern half of England, increasing to about 3½ bushels (nearly 2 cwt.) in Scotland.

When seed is sown by broadcasting, a proportion is too deeply buried and fails to germinate. If this method of sowing is practised, then it becomes necessary to apply the seed more liberally, about a bushel more being required to the acre than when it is put in with a drill.

As a rule, over-seeding results in a reduced yield of grain but an increased yield of weak straw that lodges readily; a seeding that is too thin to produce a full crop will generally give a high proportion of grain to straw. A thin seeding, however, has the disadvantage of allowing weeds to develop and spread, and a thin crop is slow to ripen. While the seed rate should provide for average conditions, the ultimate stand is largely determined by the mortality in winter and the degree of tillering. Fortunately, minor mistakes in the rate of seeding have less effect than might be expected, because when too little seed is used the plants produce more tillers and more grains per ear, whereas if too much is employed the wheat produces fewer tillers and fewer grains per ear.

The average seed-rate of 2¼ bushels per acre, given full germination, produces a stand of about thirty seedlings per square foot. The loss of plants that occurs in the winter naturally varies widely according to weather conditions, but the average is high. However, a spring stand of eight plants per square foot is capable of producing a full crop. Thin stands may be "mended" by drilling an appropriate amount of seed of a spring variety.

If wheat is sown in spring it is usually done early in March or

in February. Earlier seeding than this may be attempted if the condition of the land permits, but it should be remembered that the ravages of rooks and other grain-devouring birds become particularly severe at a time of the year when food is scarce, and it is possible that these may remove most of the seed that is sown.

The method of preparing the seed-bed will depend on the preceding crop. If wheat is to be taken after a fallow, the last fallowing operations should be designed to leave a fairly firm bottom and a rough surface mould. If the land is ploughed, only a shallow furrow-slice should be turned over, and the use of the cultivator should then be sufficient to leave the soil in a fit condition for the corn-drill. The soil should on no account be worked fine, as overworking before the winter rains may bring about the formation of a surface "cap" that prevents free aeration of the soil and is difficult to break up in spring. The ideal is a layer composed of fine crumb and small clods in the zone in which the seed will lie, with a surface covering of clods, including some as large as a man's fist.

When wheat is taken after potatoes, which leave the soil in an open, friable condition, a seed-bed can often be prepared by the use of cultivators and drags. If the land is ploughed, either after potatoes or after roots eaten off by sheep, a shallow ploughing will usually give the best results. Wheat grows poorly where there is a subsoil "pan," or where the subsoil becomes waterlogged in winter. Deeper ploughing or subsoiling may remedy either condition.

Broadcasting on the furrow is still occasionally practised, mainly in cases where the land is too wet for the drill to run cleanly. Another possibility is to broadcast the seed on the surface and plough it in with a shallow ($2\frac{1}{2}$ in.) furrow-slice. In some districts use is made of a small seed hopper which is attached to the beam of the plough and drops a thin stream of seed into the open furrow.

When wheat is grown after a crop of "seeds" the preparation of the ground is relatively simple, the wheat being drilled across the furrows, with only a small amount of preliminary harrowing or sometimes no previous cultivation. If the crop is to be sown on freshly ploughed ley a furrow press should be used to consolidate the seed-bed.

Manuring of Wheat.—Wheat has a long period of growth and a deep rooting habit, and as far as phosphates and potash are

concerned can sometimes be grown, if the land be in good condition, on the residues of previous crops and manuring. Commonly, however, some phosphate, and on light or chalk soil potash also, is applied at seed-time, preferably by combine drill. In most cases, with the possible exceptions of wheat taken after a strong leguminous crop or after a clovery turf that will decompose rapidly, the application of 1½ to 2½ cwt. of sulphate of ammonia or other nitrogenous fertilizer produces a marked improvement and a profitable return; indeed it is becoming customary to apply nitrogen up to the limit that will cause lodging. A shortage of nitrogen is frequently exhibited by a yellowing of the crop about the time when active spring growth is commencing, *i.e.* in late April or early May. Experiments have shown that the time of applying the nitrogen is important. A February application, preferably of sulphate of ammonia, stimulates tillering and thus greatly helps a thin crop, but when given to a thick crop it causes an undesirable development of straw. To improve the grain yield of a normal crop, the nitrogenous fertilizer should be applied early in May. In the drier areas Nitro-chalk or nitrate of soda is to be preferred to sulphate of ammonia. Under some systems of farming the "seeds" land is top-dressed with farmyard manure before it is ploughed for wheat, when no dressing of artificial fertilizers should be necessary. In some parts soot, at the rate of about 4 cwt. per acre, is still used as a spring dressing.

If wheat is taken after another corn crop, or after potatoes on land that is light and in poor heart, it may be desirable to apply ¾ cwt. of sulphate of ammonia with superphosphate—or an equivalent amount of concentrated fertilizer—with the seed in autumn, followed by a top dressing of nitrate or Nitro-chalk in May. The quantity of superphosphate that will give a profitable return depends mainly, of course, on the soil reserves and to some extent on the district, for it has been shown that all crops respond more to phosphate in the north and where the rainfall is heavy. If 1½ cwt. per acre suits central and northern England, 1 cwt. will probably be enough for the drier south and east, whereas between 2 and 3 cwt. may be optimal in the wetter west and in Scotland. Another point is that the phosphate may be reduced considerably where it is put in with the seed instead of being scattered on the surface (see Placement of Fertilizers). There is a risk that the benefit of the autumn application of

nitrogen may be lost because of a wet winter, and if this should happen it may pay to renew the application in February. In some cases a remarkably poor crop of wheat is grown after a very good crop of potatoes. The reason for such a failure may be that the potato crop has thoroughly exhausted the soil and the wheat suffers from starvation.

Where wheat is grown in rotation with crops such as potatoes, beet, or mangolds, which normally receive dressings of potash and dung, it will not as a rule respond to potash manures. But on light land or where the soil is known to be deficient in available potash, it may be worth giving wheat a dressing of the order of 1 cwt. per acre of muriate or its equivalent.

After-cultivation.—In spring, wheat is usually subjected to a fairly severe harrowing in order to break down clods, which readily fall to pieces after the winter frosts, and to tear up the surface "cap" that has been formed by the beating action of rain. The harrowing also drags out surface weeds, especially straggling weeds like speedwell, and is considered to have a beneficial action in separating the plants and causing them to tiller. Of course harrowing may tear out some of the wheat plants. Should the crop be thick it may be harrowed both ways, but if it be thin it is safer to harrow in the direction of the drills only. If the land be dirty with annual weeds, and the crop can stand fairly rough treatment, the harrowing may be repeated a number of times. The operation that follows the harrowing is usually a heavy rolling to consolidate the soil about the roots of the plants. Rolling across the run of the drills with a Cambridge roller is sometimes practised to check the ravages of wireworms. But where wireworm damage is feared, the best practice is to apply a BHC or other wireworm dust either to the seed or to the seed-bed (see p. 274). Where the soil is very loose and "hollow" in spring, and where the plant is not over thick, rolling should precede harrowing, otherwise the harrows will drag out too many plants. Horse-hoeing, which is of undoubted service in keeping the land clean, is still practised in some districts on a small scale, and the same result may be obtained with a tractor hoe, fitted with A-blades of suitable width. The width of the hoe must match that of the drill which has been used, *i.e.* should cover either the same or half the number of rows. To make this practicable the distance between the drill coulters must be somewhat greater than normal, *viz.* 8 or 9 in., and a steerage type of hoe (see p. 186) must be used. Hand-hoeing, a

method of cleaning adopted in the past for the suppression of strong-growing weeds, like thistles and docks, is rarely practised to-day, the objective generally being attainable by the use of selective weed-killers.

If the land is in good heart and the winter has been mild, wheat may become " winter proud," that is, it may be so much overgrown by the spring that it tends to become too heavy, and is likely to lodge before harvest. Wheat in this condition can be checked by turning on sheep or cattle and allowing the animals to graze it down fairly closely, but grazing must not be continued after the end of April. Stock should be put on only in dry weather, and then only for limited periods. Where stock cannot be had to graze down the crop, sulphuric acid spray may be used to obtain the same effect, or the wheat may be " flagged," *i.e.* the top leaf may be cut off.

Harvesting.—If wheat is cut before its time the yield of grain is reduced, and much of the food material of the plant is retained in the straw ; the sample is also poor in quality, as the grains are shrunken and small, and particularly unsuitable for seed purposes. When a crop is cut too late the sample is bold, well filled, and of excellent appearance, but the bran may be too thick to give the best yield of flour in the milling process ; this condition, however, is ideal if the grain is to be used for sowing. The chief disadvantage of late cutting is the liability of the grain to shake out of the ear, both before and during harvesting operations. When the straw, which loses its green colour from the base upwards, has assumed a distinct yellow tinge below the ear, it is time to examine the ripeness of the grain with a view to reaping. The grains should be rubbed out of a few average ears, and their condition determined by pressing them between the thumb-nails ; they will probably be soft, but, if they exude no milky juice, the crop may be considered ripe enough to be cut by the binder, when the final stage of ripening will take place in the stook. If a milky fluid can be expressed from the seed the crop should be left for a few days ; but when the grains have matured beyond this stage, cutting should commence. When wheat is to be cut with a " combine," it will need to be left for about a week after the stage indicated, and experience has shown that with most varieties this does not involve much risk of loss through shaking.

Before cutting with the binder some farmers " open roads " round the field with a scythe, so that a way is made for the machine to move without destroying any of the crop. However,

where labour is scarce the binder may be driven straight into the crop without causing very serious loss. In this case the "back swath" or outside bout, which is pressed down by the passage of the machine, is left until the rest of the field has been reaped, by which time many of the flattened stalks will have risen far enough to let the knife get under them. The back swath is, of course, cut in the opposite direction from the rest of the field. With the self-propelled combine, which has the knife in front, the problem naturally does not arise. Nearly all the corn crops of the country are now cut with a binder or combine harvester, but neither of these machines is completely satisfactory unless the crop is standing well. Should the wheat be leaning in one direction, so that the machine travelling in that direction simply pushes the straw farther over, and either does not cut it or leaves too long a stubble, the machine should be used to cut one way—against the direction of lean—and then driven back to the starting-point with the mechanism out of gear. The "pick-up reel" available for the combine is a great advance on the traditional pattern for dealing with lodged crops. It may be possible to cut a crop with a reaping-machine or a mower when it cannot be cut successfully with the larger implement. If patches are badly laid (see p. 305) in all directions it may still be worth while, if the labour can be obtained, to cut them with the scythe or hook and bind by hand; a good scythe-man and two binders are capable of clearing about an acre per day, which is a laborious business when it is considered that a mechanical reaper and binder can perform the same amount of work in an hour. Cutting with the binder should not take place if the crop is wet with rain or dew, as not only do the canvases tend to shrink and jam, but the excess of moisture in the tightly bound sheaf causes undue delay in drying. Combine harvesters also require the crop to be in dry condition and, if possible, free from juicy weeds. If the latter are present in quantity they tend to clog the threshing mechanism. In this case the crop may be cut and left in windrows and afterwards picked up and threshed by a combine with a "pick-up" attachment.

After the crop has been bound the sheaves are arranged so that they may dry as quickly as possible, and at the same time be able to withstand a spell of inclement weather. This is done by setting them up in shocks or stooks, each stook consisting of ten or twelve sheaves, half on one side and half on the other, arranged as far as possible in rows running north and south so that each side obtains

equal benefit from the sun. Pains should be taken to plant the sheaves with their oblique butts firmly on the ground and their heads in close contact, or the whole erection is likely to topple over in a slight wind and much labour will be required for resetting. Daily resetting of the stooks is essential during periods of mild and wet weather if the quality of the grain is to be preserved. If the crop is undersown, the stooks must not be allowed to stand long enough to damage the underlying grasses and clovers.

As a rule the crop is ready for carrying in from four to fourteen days after cutting. This period is required for the proper drying of the straw, because if too much sap is present when the crop is stacked heating and moulding will ensue and the germination will be spoiled. In order to ascertain when the crop is ready to carry, a few straws should be taken from the middle of the sheaf and examined at the nodes. When these have become hard, shrunken, and concave in outline, it may be taken that the straw is sufficiently dry. When too much sap is present the nodes are soft, juicy, and convex. Care should be taken to examine the straw in all parts of the field, as a portion of the crop in a hollow or sheltered situation may still retain too much moisture when all the rest of the corn is fit to carry. If the farm, or particularly the stackyard, is in a wooded or a sheltered situation, the greatest care must be taken to ensure that the crop is in a thoroughly dry condition. If, on the other hand, the stackyard is placed on an elevated site, swept by the winds from all quarters, the same care is hardly necessary, as the risk of heating is greatly reduced. A rattling or crackling of the straw when it is being carried, and a certain looseness of the sheaf within the twine, indicate that the crop is in excellent order for stacking. When once the crop is dried, a shower of rain should not be allowed to hinder the carrying operations, as the surface moisture will do no harm; in this respect wheat is more easily managed than the other cereals.

The method of carrying the crop depends on the local custom, the type of cart employed, the style of stacking, and the number of hands available for the different operations. A simple and economical method is to employ one man as builder of the stack, one man to fork the crop in the field, and two or three single-horse carts (the number depending on the distance between the field and the stackyard) to drive in the crop, each driver building and pitching his own load. But if the stack is large the builder will need an assistant.

Different types of stack are built in different districts. In the north it is customary to build stacks small and round ; in the south they are sometimes made very large, and are, as a rule, rectangular in shape. Whichever method is employed, it is wise to lay out the stackyard with great care, always bearing in mind the possibility of pitching directly from the stacks on to the platform of the thresher, the accessibility of the first varieties to be threshed, and the reservation of the outside and exposed positions for crops that have been secured before they were in a proper condition. Building in the bays of a Dutch barn saves time by avoiding the delay that occurs when " topping out " stacks ; in addition, no thatching is required.

When the completed stacks have settled, and when sufficient time has elapsed to ensure that there is no possibility of heating, they should be thatched with sound wheat or rye straw, and the thatch well secured with ropes, or strings and pegs. The appearance of the stacks will be greatly improved if the outside is pared or trimmed to remove all loose straw and the protruding " tail " ends of the sheaves. This also saves a small amount of corn that otherwise would be eaten by birds or damaged by weather.

(For threshing, see Part I : Threshing, Combine Harvesting.)

Yield.—The average yield of wheat in Britain is over 20 cwt. ($4\frac{1}{2}$ qrs. of 504 lb. per qr.) to the statute acre. Crops of 30 to 35 cwt. (7 to 8 qrs.) are, however, grown on good land, and yields of over 60 cwt. have been recorded. The highest authenticated British yield is $70\frac{1}{2}$ cwt. The weight of straw is about one and a half times that of grain ; that is, the total produce is 40 per cent. grain and 60 per cent. straw. The proportion, however, varies within rather wide limits and is notably lower, as would be expected, in the newer, short-strawed varieties. The bushel weight averages 63 lb.

FUNGOID DISEASES OF WHEAT

Bunt.—A casual examination of the ear of an affected plant does not reveal the presence of this disease, but when the grains are removed and broken they are found to consist of a mass of black spores, giving off a strong fishy odour. When threshing takes place the affected grains burst, discolour the healthy wheat, and impart to the whole an objectionable odour. In this way not only is the yield of grain diminished but its value per cwt. is

greatly reduced. If wheat is sown with spores of the fungus adhering to the grain, the seeds and spores germinate together and the fungus finds its way into the reproductive shoot, finally destroying every grain in the ear.

The disease can be prevented by dressing the seed with a suitable fungicide, a solution of formaldehyde being at one time largely used for this purpose. Dry disinfection of seed is now almost universal; its advantages are that it is very safe and that the seed, if in good, dry condition, may be dressed a long time before it is to be sown; indeed, most merchants send out their seed already treated. Bunt may be checked by powdering the seed grain with dry copper carbonate, but in practice the proprietary seed disinfectants containing organic compounds of mercury are now in general use for controlling this and other seed-borne diseases. The dry dressings are all used at the rate of from $1\frac{1}{2}$ to 2 oz. per bushel, but good dry seed is not injured by rather larger doses. The success of the treatment depends on the complete spreading of the powder over the surface of the grain, and mixing should therefore be done in a machine or revolving container. An old butter-churn will serve as a mixer, but some special machines have an eccentric motion which makes their action very thorough. While most machines have to be emptied after each batch has been mixed, there are mixers constructed on a continuous flow principle; that is, the grain and disinfectant are fed in continuously and emerge in a well-mixed stream. As the dusts are irritating to the nose and lungs, masks should be employed by workers who have to handle large batches of material, and the treatment should preferably be in closed containers.

Loose Smut.—This fungus attacks the developing ears in such a way as to destroy the flowers completely, and also the pales and glumes (chaff). The whole head of the plant becomes covered with a black mass of spores. It is not possible to prevent the recurrence of the disease by dusting infected grain, as the mycelium of the fungus is present inside the apparently healthy seed. Although the fungus can be killed by immersing the seed for ten minutes in water at 128° F., this treatment is difficult to carry out in practice, and the best way to avoid further attacks is to obtain seed from an unaffected crop.

Yellow Rust.—This is a very common disease of wheat in this country. Affected plants can be recognized by the bright yellow spots on the leaves and chaff: these spots represent patches of

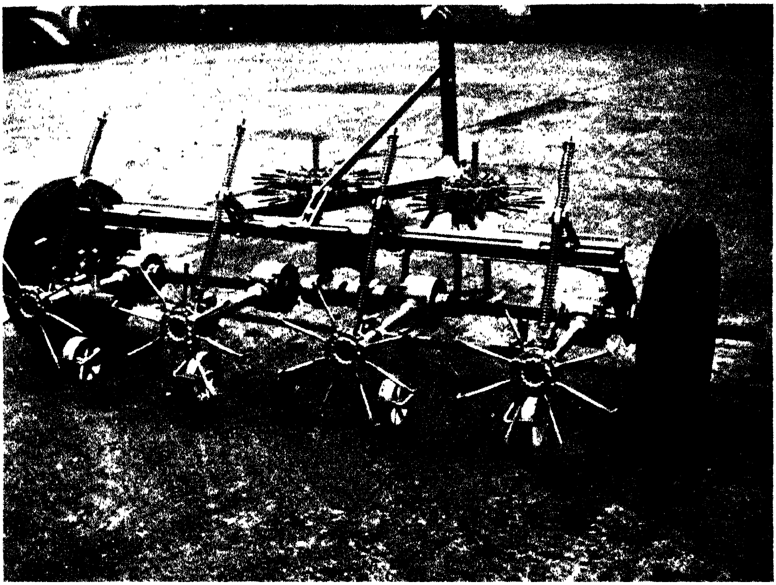
leaf surface through which the spore-bearing organs of the fungus have burst, and the yellow powder issuing from the ruptures consists of spores. The grain of rusted plants does not fill properly, but remains small and shrunken like wheat that has been cut prematurely or has been grown in a district too late for it to ripen.

There is no known preventive measure that gives absolute immunity from rust attacks, but there are varieties of wheat that exhibit a much greater power of resistance than others. The best-known rust resister is Little Joss.

Brown Rust.—While yellow rust may be found on wheat at all times from early spring to harvest, and even on young plants in autumn, brown rust is first seen about the middle of June when the grain is beginning to fill. The fungus destroys the foliage and prevents the ears from developing properly. Wheats which resist yellow rust do not necessarily withstand the attacks of this species; but there is reason to believe that should brown rust become more prevalent, resistant wheats could be produced. At present brown rust is not very widely distributed.

Black Rust.—This is the well-known wheat rust of America and India which for a long time was believed not to exist in this country but is now known to be sparsely distributed. In this rust the spots do not occur on the leaves but on the stem, and the spores are of a very dark, almost black, colour. The black rust fungus has a second host, namely the common barberry, on which it passes part of its life-cycle. If the wheat of a district becomes affected with the disease, the barberry bushes should either be removed—a measure that has met with great success in U.S.A.—or varieties of wheat should be found that are resistant to the fungus.

Take-all.—This is a disease of wheat and barley—oats are relatively immune—which causes the plants to die early and produce typical "whiteheads" with little or no grain in the ear; but by harvest-time the straw becomes blackened at the base owing to the formation of a felt of mycelium. The fungi remain on the stubble and in winter or early spring produce spores which are capable of reproducing the disease in young wheat plants. This disease is most prevalent on soils that are low in organic matter and high in lime, and is likely to be serious only where wheat and barley are grown year after year, or in very close rotation, on the same ground. The worst outbreaks are in wheat that follows either barley or wheat. Oats are scarcely affected.

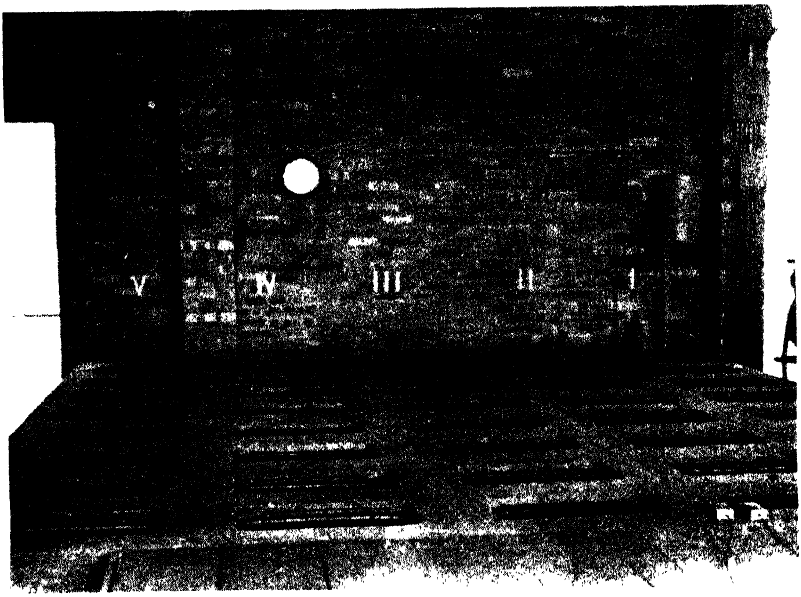


A. Down-the-row Thinner

B. Swathing Machine

PLATE XXVI

A. BASE OF VENTILATED GRAIN SILO UNDER CONSTRUCTION, SHOWING: (a) VENTILATING DUCT; (b) PLENUM CHAMBER; AND (c) FOAMED SLAG BLOCK FLOOR



B. IN-SACK GRAIN DRYER

The remedy is to adopt a system of cropping that will starve the fungus out. In this respect it should be noted that couch-grass, Yorkshire fog, and bent-grass all perpetuate the fungus, but the disease is usually found to decline under a rye-grass and clover ley. Where wheat is to follow wheat it is a good practice to burn over the stubble of the first crop. The damage is greatest under conditions of low fertility, so that the liberal use of fertilizers is to be recommended when there is reason to fear an attack.

Eye-spot is caused by the fungus *Cercosporella*. In serious cases the fungus, which attacks the base of the stem, causes the lodging of the whole crop. The only effective preventive measure is again the adoption of a suitable rotation. In some respects, however, the problem of eye-spot is different from that of Take-all. Firstly, its incidence is greater on heavy than on light land. Secondly, susceptible crops (wheat and barley) must be kept off heavily infected land for at least two seasons and for three if, during the first of these, there was any considerable amount of self-sown wheat or barley. Thirdly, the common grasses do not act as host plants for the fungus, so that the first crop after old turf is usually very clean. In this case a second crop of wheat can be taken with safety. The disease rarely causes heavy damage except to winter wheat.

Powdery Mildew caused by the fungus *Erysiphe graminis* affects not only wheat but other cereals and many grasses. It is usually to be found on wheat towards harvest time, but serious damage is caused only from an early attack. These early attacks occur mostly when a dry spring follows a mild winter. Excessive use of nitrogen fertilizers makes the crop susceptible to attack. Varieties vary in degree of susceptibility.

INSECTS AND OTHER PESTS

Wireworms.—These are the larvæ of several species of click beetles, which formerly caused enormous damage in both farm and garden. Among major farm crops those which suffer most severe damage are wheat, oats, and potatoes. Barley, perhaps because it is often sown in late spring and therefore quickly grows beyond the seedling stage, is less liable to disastrous damage. Beans and flax are highly resistant.

Wireworm population tends to increase while land is under grass and to diminish under continued arable cropping. Damage

to grass swards is not very noticeable even when very large numbers are present, because established plants can quickly repair root damage. On the other hand a wheat seedling is killed if the lower part of the stem is eaten through just below ground level, which is the usual form of attack.

When a cereal—and especially a spring cereal—is sown on freshly ploughed turf, it may escape damage because the wireworm continues for a while to feed on the turf, and in the meantime the crop becomes well established. In such cases the second arable crop after grass may suffer more severely than the first. But if the first crop is winter wheat, or spring wheat sown on a stale furrow, it will usually suffer very severely in spring if the wireworm population is high.

Entomologists have evolved a technique for estimating the number of wireworms per acre, and are able to predict the chances of success or failure of a given crop. For example, with a population of 750,000 it would till lately have been unwise in most areas to attempt winter wheat or spring oats; but barley, sown rather late on a very well-prepared seed-bed, would have quite a fair chance of success. Beans or flax would be quite safe.

The situation has, however, been radically changed since the introduction of BHC—the gamma isomer of benzine hexachloride. The application of this material, either to the seed-bed or to the seed itself, which can be done at very moderate cost, is a cheap insurance against loss. Seed-bed treatment should be preferred to seed dressing in cases where infestation is really heavy.

The bean crop, apart from the fact that it is almost immune, seems to have the effect, so far unexplained, of reducing the wireworm population of the soil in which it grows. Wireworms are naturally kept in check by insectivorous birds, and these should on no account be destroyed nor their nests disturbed. Wireworms are easily destroyed by drying, and a large population may be reduced by fallowing in spring and early summer.

The following insects are also injurious to wheat and other cereals: the wheat bulb fly, which, because the fly lays its eggs on bare ground from July throughout August, is worst when the crop is taken after a fallow (but attacks are not uncommon after potatoes and peas), the frit fly (see p. 291), the gout fly, the Hessian fly, and the wheat midge. All are difficult to suppress, and may cause serious damage. Early sowing is, however, helpful in cases where bulb fly seems likely to cause trouble.

For fuller particulars of treatment and remedial measures the reader is referred to the Ministry of Agriculture leaflets or to works on Entomology.

Slugs may become so numerous that they cause damage to wheat; they can also cause serious losses in other crops. They may be poisoned by applying to each acre ½ lb. of metaldehyde mixed with 25 lb. of bran. Cutworms or surface caterpillars, the larvæ of a number of species of moth, eat through the stems of wheat, and eat the stems and leaves and hollow the roots of other crops. They may be poisoned with Paris green as in the case of "leather jackets" (see p. 290).

OATS

The oat is the most extensively cultivated cereal in this country, and is grown in every county and under widely different conditions of soil and climate. While not as resistant to winter cold as wheat and barley, oats are much more successful than these cereals in wet districts. The varieties now cultivated in Britain nearly all belong to the species *Avena sativa*, which is derived from *Avena fatua*. Some of the varieties grown in hot countries are derivatives of another wild species named *Avena sterilis*. Varieties of *Avena strigosa* are still to be found in late and cold districts such as Shetland and in the upland parts of Wales. The spring wild oat, *Avena fatua*, is a worthless annual weed which infests the corn crops in many localities where winter-sown cereals are very frequently grown. The winter wild oat, *Avena ludoviciana*, introduced about 1930, is another troublesome weed.

In the economy of the farm the oat crop fulfils a dual purpose: it is a producer of feeding grain and at the same time supplies straw that is superior to all other cereal straws in palatability and nutritive value, and is largely used to replace hay in winter feeding of stock. The superiority of oats as food for horses, especially for fast work, has long been recognized. The feeding of crushed oats to cattle and sheep gives good results, but the grain is not of a sufficiently nitrogenous nature for milking or young growing animals unless supplemented by other concentrates, and should be blended with a food rich in protein—for example, bean meal or linseed cake. When calves, at about a month old, are changed over from a whole-milk diet to separated milk, oats, at the rate of 1 lb. to 1½ gals., form a good fat-substitute. Crushed

oats are used in the feeding of sows and fattening pigs, but if the grain is to be used as a feed for very young pigs it should be employed in moderation, because its fibre-content is rather high, and it should be finely ground. The feeding of new oats is always attended by a certain amount of danger, and old oats, or at least such as have been matured in a well-settled stack, are to be preferred in stock dietary. Large quantities of oats are, of course, used for human consumption in the form of rolled oats, oatmeal, etc.

Milling of Oats.—In the manufacture of oatmeal the first process is to screen the oats thoroughly in order to remove impurities. The grain is then heated in a kiln until its moisture-content, which is normally about 13 per cent., is reduced to about 2½ per cent. Shelling is next carried out by passing the oats between revolving horizontal stones which rub the husks away from the kernels. The material issuing from the stones is then treated to remove the dust and the husks, while the kernels or groats, after a special scouring to remove the external fibrous layer, pass to a stone mill for grinding. The ground oats are sorted through sieves into meals of various grades of fineness such as round, medium-cut, and fine-cut oatmeals. The yield from 100 lb. of oats is about 60 lb. oatmeal, 17 lb. husks, and 9 lb. of dusts and residues from the sorting screens; the remaining weight is lost in the process of cleaning and drying. The oat husks are of practically no value for feeding but are used as litter for poultry, by brewers as a mechanical aid to the draining of their mash, as packing, etc. The oat dusts and screenings may be used in mixture with other foods for stock.

Rolled oats are prepared by rolling out and drying the kernels after they have been softened with steam.

Quality of Oats.—High quality oats are plump and well filled; they have a minimum of husk and a high bushel weight. In British-grown samples the percentage of husk, by weight, varies between extremes of about 22 and 28 per cent., and bushel weights for unclipped grain run from about 37 to 48 lb. for grain in good dry condition. The highest bushel weights and lowest proportions of husk are obtained when the crop ripens slowly in cool weather. The colour should be bright and there should be no indication of heating or sprouting; there should be no shelled grains, weed seeds, or other impurities. Oats grown in the cooler and wetter parts of Britain seem to have a higher proportion of oil and protein in their composition, and this may account for the acknowledged superiority of Scotch oats for milling purposes.

The best oat straw is fine and grass-like, and has a higher nutritive value than poor hay, but some varieties are so coarse in the stem and leaf that they are not only innutritious but also unpalatable. In order to secure the best fodder one of the noted straw-producing oats should be grown, or the crop can be cut before it is ripe so as to stop the transference of nutrients from the straw to the grain and check the lignification of the cellulose which occurs in the later stages of ripening. The proportions of grain and straw differ in different oats, and as a rule those varieties which give a high proportion of their yield in the form of straw also produce straw of fine quality.

In aiming at the greatest profit per acre the farmer looks for a variety that produces a high yield; but he has also to select, according to the needs of his stock or the demand of the market, either a variety that will give him an abundance of good fodder for home consumption or one that will yield a maximum of corn for sale. Unfortunately these qualities are somewhat antagonistic and cannot be fully combined in a single variety.

As mentioned above, the oat crop is grown under a wide range of conditions. At times it is grown on land that is fat with the residues of heavy manuring, when there is a great risk that the crop will be laid and will suffer heavy loss. To reduce this risk to a minimum, a variety should be grown that is either short or very strong in the straw. On the other hand, the sort of oats that will yield best under good conditions of soil and climate may give poor results when sown in an elevated or late locality—either because the plants are not sufficiently hardy, or because they take so long to mature that the crop cannot be ripened or got into sufficiently dry condition for stacking in the normal season. Earliness is specially important, in late districts, where the crop is to be undersown with grass and clover.

The capacity of the variety for tiller formation is important because of its influence on the amount of seed that is required. Under adverse conditions a large proportion of the seed fails to produce plants, and consequently the poorer the land the greater the need for a thick seeding or, on the other hand, a good tillering variety. Our largest-grained oats have the poorest tillering capacity, and on poor soil or at high elevations the cost of seeding these varieties is a disadvantage. Where the stand is poor not only will the yield be diminished but ripening will be uneven and greatly delayed.

If oats are being grown for home consumption it is immaterial whether the natural colour of the grain be white, yellow, grey, or black. In districts where oats are largely sold for seed, however, any lack of purity with regard to colour will render a sample unsaleable except for feeding, and consequently the greatest care must be taken when varieties of different colour are being threshed by the same machine. Yellow oats are often popular in late districts where the rainfall is heavy, because under these conditions white oats tend to acquire a dull colour, while slight weathering can hardly be detected in yellow-grained varieties.

Varieties.—The number of oat varieties in cultivation is very large, and since the crop is grown under a very wide range of environmental conditions, from the poorest to the most fertile soils, from Shetland in the north to Kent and Devon in the south, and under annual rainfalls of 20 to perhaps 70 in., it will be obvious that a wide choice of types is desirable. At high elevations in Scotland and in Wales even the earliest varieties do not reach full maturity, and the crop is commonly fed to livestock in the form of oat sheaves. Moreover, in the moister areas generally, oat straw has a high feeding value, and the farmer therefore thinks in terms of total yield rather than of grain only. Under such conditions leafy and small-grained types of *Avena sativa* and sometimes of *Avena strigosa* are cultivated.

In the drier areas the straw becomes highly lignified and is hence of little value as fodder. Under such conditions the farmer's main consideration is the yield and quality of the grain.

There is a fairly sharp distinction between true winter varieties (which are normally sown in October and are usually ripe for harvest before the end of July) and the spring varieties, for which seed-time ranges from late February to the middle of April and which ripen from early August to late September, or even as late as October in the extreme north.

Winter Oats.—These are sufficiently frost-hardy to survive average winters throughout the south-eastern half of England except, of course, in elevated districts; they can also be grown without serious risks in areas near to the seaboard farther north. No winter oat so far produced is, however, as frost-resistant as the general run of winter wheats; in the south Midlands, where loss of wheat by frost is very rare, even the hardiest winter oats are occasionally winter-killed, perhaps as often as one year in seven. The winter-oat seedling has a characteristic prostrate habit of

growth and the shoots do not assume an erect habit until active growth commences in the spring. Most varieties tiller very freely so that a relatively small seed-rate is sufficient to produce a full crop. Since the plants are usually well rooted by the time when drought is liable to occur, winter oats give higher yields than spring varieties in the drier districts. Moreover, they are much more resistant than spring oats to attacks of frit fly, which can be a major cause of damage to spring varieties in the south-eastern half of the country. The point is that autumn-sown plants have passed the susceptible stage of growth by May, which is the egg-laying season of the fly. A difficulty in growing winter oats in districts where the practice is uncommon is that the crops become attractive to sparrows and other small birds before the general run of cereals have reached this stage. The damage is greatest in the neighbourhood of towns, but even in country districts birds tend to flock to winter oat fields.

Six winter varieties are worthy of mention, and of these three are widely cultivated. It is worthy of note that all of these have been bred in Britain whereas a large number of the commonly grown spring varieties are products of Swedish plant-breeding stations.

Grey Winter was, until recent years, the most widely grown sort. The grain is small but very thin in the husk, and of high feeding value. The straw is long and fine, and of high value as fodder, but so weak that any attempt to obtain a high yield, by the generous use of fertilizers, results, in a normal year, in lodging. With the recent tendency to more intensive manuring, and with the introduction of other equally frost-resistant types, Grey Winter has rapidly declined in popularity.

Black Winter, another old variety, was sometimes preferred to the last-mentioned type because of its stronger straw, and despite its considerably lower frost resistance. It also has been replaced by newer sorts.

Unique (Garton) is like Grey Winter in most of its characteristics but is white-grained and slightly stronger in straw. It can be recommended only for land of low fertility.

Picton (Cambridge Plant Breeding Station) and *Aberystwyth S.* 147 are the most useful varieties for average conditions. Both have large white grain and long but stout straw. Both are very nearly or perhaps quite as frost-resistant as Grey Winter. The quality of grain is hardly as fine, but this disadvantage is

far more than compensated by their greater productivity—the difference under good average conditions being of the order of 20 per cent. Of the two, S. 147 produces rather the more palatable and nutritious straw and is more resistant to lodging, but it is susceptible to damage by stem eelworm.

Aberystwyth S. 172 is markedly different from the last. The grain is white and small with a medium husk and the straw is both very short and very stiff. This variety responds well to generous manuring and is to be recommended for good soils that are in high condition. On poor, thin soils, such as those of the chalks and oölites, it yields poorly, especially in dry seasons; in extreme cases the straw is so short that the ordinary binder cannot be set to tie the sheaves.

Spring Oats.—Many attempts have been made to classify the great number of spring varieties commonly or occasionally cultivated, and botanical characters such as colour of grain, type of panicle, etc., have sometimes been used. The most useful classification is, however, according to the environments to which the varieties are adapted, and the most important environmental factors are on the one hand the fertility of the soil and, on the other, the combination of rainfall and temperature that together make particular areas "early" or "late." Naturally, environments are not sharply defined, so that a particular variety may appear in more than one of the following groups.

(1) First we may place the varieties suited to cold and wet climates and poor soils—conditions that are common in the upland regions of the north and west. For the most extreme conditions, where great hardiness is essential and where marketability is unimportant because the crop is grown exclusively for consumption by the farmers' own livestock, the two Aberystwyth sorts, S. 171 (Ceirch Llwyd Cwta) and S. 75 (Ceirch Llwyd), are of value. The latter is a pure-line selection of the old bristle-pointed oat (*Avena strigosa*) while the former is a hybrid of the latter species with *Avena brevis*. These two are marked improvements upon the older types of *strigosa* oats which were once largely grown in Scotland and Wales and which still survive in Shetland and the Hebrides as well as in the higher Welsh valleys. Under somewhat less extreme conditions *Black Tartarian* and other old varieties such as *Sandy* and *Bell* are still grown to a limited extent.

(2) For wet and cool areas with soils of moderate fertility the

most widely grown varieties are *Scotch Potato*, *Yielder* (Garton), *Radnorshire Sprig*, *Aberystwyth S.* 220, *Craigs Afterlea*, and *Golden Rain* (Svalof). The Potato oat produces grain of unsurpassed quality for milling and the straw is highly palatable and nutritious; but the straw is weak and, apart from this difficulty, the variety does not respond well to generous manuring. The variety is very leafy and throws so dense a shade that it is unsuitable as a nurse crop for grass seeds. There are some reselected types such as *Castleton Potato* and *Pure Line*. Yielder is rather shorter and much stiffer of straw and is, moreover, much earlier ripening, all of which characteristics favour its use as a nurse crop. Yielder can be grown on better land and is in fact widely cultivated in the lowlands of north-eastern Scotland, but mainly with the object of producing seed for upland farmers. On light soils in the drier districts it tends to ripen prematurely, and to yield poorly, in dry seasons. Golden Rain, which has yellow grain, yields well, is not apt to lodge, and produces a useful quality of both grain and straw. It is a favourite variety in the dairying and stock-rearing areas of north-western England. Radnorshire Sprig is a hardy, early black variety which was popular in many parts of Wales, but should be displaced by S. 220 which is less susceptible to lodging. Craig's Afterlea is also relatively stiff-strawed.

(3) For general cultivation in lowland areas, and especially under the lower rainfalls of the south and east, there is a wide choice. The following constituted the N.I.A.B. recommended list at the time of writing:—

Eagle.—A white oat with a rather small, open head. Eagle has given appreciably higher yields than Victory, and its straw stands better. Its grain is rather small, but has a thinner husk than Victory. Recommended for general cultivation, particularly on good soils.

Sun II.—Bred at Svalof, Sweden, from Star and Eagle. A white oat with a small open head and rather small grain. Sun II ripens slightly earlier than Victory, has shorter straw, and gives heavier yields of grain. Recommended for general cultivation.

S. 84.—A white oat valuable for its strong straw. In trials south of the Humber it yielded slightly less than Victory and was late-maturing, but it showed a high resistance to lodging.

Milford (S. 225).—A white oat with an exceptionally short and stiff straw ripening about the same time as Victory. The yield

is not superior to that of Victory, except where lodging occurs. The grain is small but has a thin husk. Recommended for use where lodging is expected with other varieties.

Maldwyn (S. 221).—Bred at the Welsh P.B.S. from Victory and Radnor Sprig. A white oat with a small open head and small grain. Maldwyn ripens earlier than Victory, has shorter straw, and gives heavier yields of grain. It tillers freely and gives good results at low fertility levels as well as on better soils and is provisionally recommended.

Victory.—A white oat with a rather small, open head. A reliable variety for soils of average to low fertility.

Star.—A white oat with a rather small, open head. Star has all the merits of Victory with a thinner husk and a better standing straw. Recommended for general cultivation on soils of medium fertility.

Onward.—A white oat with a one-sided somewhat open head and straw of medium length. It matures very early and gives high yields of short, plump grain with a thick husk. Likely to be superseded by *Forward* which is similar in character but more productive.

THE CULTIVATION OF OATS

Soil and Climate.—The oat is the best of our commonly cultivated cereals for growing on poor soil, in dull rainy districts, and where the summer temperature is rather low; it can be ripened by a minimum of sunshine. Very high rainfall encourages the development of straw rather than grain. Lower rainfall and better soil lead to the development of more and better grain but less straw of lower feeding value. The oat crop is apt to be a failure in dry districts, and high temperatures cause it to ripen prematurely and produce thin, light grain.

In the fens, where the rainfall is low, very fine crops of oats can be grown because the soil receives a constant supply of moisture from the high water-table. A clay loam that is supplied with abundant moisture is the best all-round soil for this crop, but black-top and peaty land give almost as good results. Should a soil suffer from lack of lime, oats will be affected much less than either barley or wheat.

Place in Rotation.—In the northern and western districts of Britain the oat crop is usually the first taken after ley or broken-up

old pasture, as no cereal does better on decomposing turf. Even after one year's " seeds," oats are preferred to wheat, because, while wheat may do equally well, the fact that oats are, as a rule, spring-sown, makes it possible for the aftermath to be grazed right up to ploughing-time in December or January. In the southern districts oats are frequently taken after potatoes or roots, but more often as a second cereal, following wheat. In some clay-land localities of high rainfall where roots are never grown, and yet where the pasture wears out and has to be re-seeded from time to time, two crops of oats are taken, one after the other, the grass seeds being sown with the second.

Preparation and Sowing.—On ordinary lowland arable farms oats are treated like other cereals. In upland areas, where the total tillage area and also the individual fields are small, and where steep slopes make for difficulty, traditional methods (including hand-sowing) still prevail. When the crop is to be taken after lea, the land is carefully ploughed about December, so that the furrows may be exposed to the frost and thaw of winter, and will be easy to work into a tilth when seed-time approaches. The ploughing of lea is usually attended with more care than any other ploughing operation on the farm, because the land has to be turned over so that all the turf is completely buried. Also, where the seed is to be broadcast the furrow-slices have to be carefully laid so that they form regular grooves of uniform depth to receive the corn. Regular, prominent furrow-slices are got by fitting special lea shares and coulters to the plough, which cut each slice so that it stands up sharply on edge. Care is also taken to ensure that the slices are well packed together and that no spaces are left into which the seed may fall and be so deeply buried that the shoots of the seedlings will fail to reach the surface. Where inexperienced ploughmen have been employed, and gaps exist between the furrow-slices, broadcasting can still be carried out if the field is given a light harrowing, in the direction of ploughing, in order to fill up the crevices. When the land has been prepared in this way the next operation is to sow the seed, either by hand or by means of a broadcasting machine. Spring oats are sometimes sown in February, but more often in March or in the north in early April. As a good man with a couple of helpers to carry the seed for him can sow as much as 25 acres in a day, little time need be lost in the seeding operation. The broadcast seed is next covered over by a number of harrowings with ordinary zigzag

harrows, the number depending entirely on the nature of the soil; light soils require very little working, but heavy soils may require up to eight or nine harrowings before the necessary fineness of tilth is obtained. Whatever the condition of the soil, the first harrowings should be in the direction of the furrows, otherwise the tines tend to catch in the undecomposed turf, pulling the slices a little apart and so allowing the seed to slip down too far.

In lowland areas the broadcasting of corn has quite gone out of practice and the seed is put in with the drill. If this method of seeding is followed it is unnecessary to take any great pains in the ploughing of the lea, provided the turf be well covered and the land turned over in time to benefit by frost. In this case the seed-bed has to be prepared before drilling commences, and the necessary tilth can usually be obtained by the use of harrows alone. When oats are taken after fallow or roots the land is ploughed, cultivated or disked, and harrowed as often as is necessary to obtain a tilth for drilling.

As in the case of wheat (see p. 263), the rate of seeding depends on the time of sowing, the condition of the tilth, the method of sowing, the risks of bird damage, the tillering power of the variety, and the size of the seed. In areas where Leafstripe formerly caused loss of plant, very heavy seedings used to be employed, but loss can be prevented by seed-dressing. Obviously some of these factors are difficult to forecast, and in practice sufficient seed is used to meet all normal risks, even if this should be wasteful when conditions turn out to be favourable. However, there need be no guesswork about the effect of the size of the seed, for it is easy to count the grains in an ounce or so, to allow for the germinating capacity of the sample, and to sow a quantity which represents a definite number of viable seeds. The average requirement per acre has been put at $2\frac{3}{4}$ million, a figure which should of course be modified according to experience, the method of sowing and other relevant factors. The following figures, taken from the records of the Scottish Society for Research in Plant Breeding, represent the weight of seed required to sow a number of varieties, common at the time in question, at $2\frac{3}{4}$ million per acre. As all the seed was grown under identical conditions on the Society's ground, and threshed with the same outfit, the figures should be fairly representative of varietal differences.

Variety	Lb. per Acre	Variety	Lb. per Acre
Sandy	150	Victory	200
Elder	157	Star	209
Potato	164	Marvellous . . .	244
Eagle	190	Yielder	244

These figures are equivalent to about 4 bushels (1½ cwt.) per acre for a straw-producing oat, 5 bushels for an average grain producer, and 6 bushels (2¼ cwt.) per acre for large-grained varieties of the Tartarian type. In the south of England the rate of sowing for an average spring variety may be as little as 3 bushels per acre, and Grey Winter may be sown at between 2½ and 3 bushels per acre, but these relatively low figures may be due in part to the seed being rather smaller than that grown in the north. At any rate the average spring seeding for the country as a whole is probably about 4½ bushels. For broadcasting as compared with drilling, an allowance of 20 per cent. more seed may be necessary.

Oats are frequently grown with beans, peas, or tares as a mixed crop, which can be either consumed green, ensiled, or ripened for threshing. The oats and peas or oats and vetches may be mixed and sown together, the quantity of oats being from two to four times that of the pulse ; but if oats and beans are grown for threshing some prefer to sow the beans about three weeks before the oats, as the former take longer to ripen. Recent experiments confirm the traditional view that the total yield from such mixed crops is greater than that which would be obtained (from the same acreage) with separate sowings of the components. A mixture of oats with one or other of the legumes is a convenient way of producing feed grains with a tolerably high protein content.

It is found that the oat crop benefits more from a change of seed than do the other cereals. If badly ripened seed is used the yield is inferior, and it is therefore necessary, on poor farms and in late districts, to obtain fresh seed from time to time from a locality where the crop attains perfect development and maturity. In a late district it is common for seed to be renewed from an early district at least every three years, and even on good land a change may produce beneficial results. It is very probable, however, that the need for change of seed in certain districts is due to the incidence of seed-borne diseases, which can now be checked by seed disinfection (see pp. 289-290).

A common problem on rich land is how to manage the crop to prevent lodging. Experience has shown that the risk is reduced by selecting a strong-strawed early-maturing variety, by using plump and well-grown seed, by early sowing and the use of a comparatively light seeding, and by using fertilizers to balance the soil nutrients and so promote early ripening (see p. 305).

In areas where winter oats are grown it is usual to sow a week or two earlier than winter wheat. Late-sown winter oats often give poor yields, but may be preferable to spring crops in areas prone to spring droughts and frit-fly atacks.

Manuring.—While the oat crop is capable of producing a fair yield on very poor soil, it nevertheless responds to liberal manuring, and it is common to treat it with nitrogenous, phosphatic, and under certain circumstances, potassic dressings. A common treatment is to give 1 to 3 cwt. of superphosphate according to local conditions (see manuring of wheat), up to 2 cwt. of sulphate of ammonia at seed-time, and if the soil is light, an addition of 2 cwt. of kainit applied a month or so before sowing. The limit up to which manure can be profitably applied is determined by the liability of the crop to lodge when it becomes too luxuriant, and a short, strong-strawed variety can be given a much heavier dressing than one having long and slender stems.

On good soils that are in high condition, first-class crops of oats can be grown without the application of any manure; but if the soil is in particularly good condition and there is a danger of the crop becoming laid, it may be advisable to apply 2 cwt. of superphosphate to hasten ripening and 2 cwt. of kainit to balance the other nutrients. If oats follow another straw crop a liberal dressing of artificials will certainly be required unless the first crop was taken after a very rich old pasture. As a rule farmyard manure does not give good results when used for this cereal, as it encourages over-development of the vegetative parts, delays ripening, and decreases the yield of grain. If oats are suffering from the attacks of frit fly, stem eelworm, or "leather jacket," the application of a quick-acting nitrogenous fertilizer to hasten the growth of the young plants over the critical stage should never be overlooked, even if the soil is in good enough heart to warrant the expectation of a good crop without manuring.

After-cultivation.—The oat crop is usually rolled, either immediately after sowing or when plants are a few inches high, in order to consolidate the soil about the plant roots. In some cases

strong-growing weeds may be suppressed by spudding; but if the land is very foul with small annuals a few light harrowings may be given when the plants are in the young stage. It should be noted, however, that the harrowing of oats is considered to be distinctly risky in some parts of the country, though it may be practised in others when the crop is thick enough to stand it. Spraying should be resorted to in order to suppress infestations of weeds such as charlock (see p. 164).

Harvesting.—The degree of maturity that the crop should be allowed to attain depends on the use to which it is to be put. Where a high value is placed on the straw for feeding purposes the crop is cut early—when there is just a shade of yellow over the field—because at this time the food materials have not all passed out of the leaves and shoots, and the stem has not become woody. Early cutting, of course, interferes with the development of the grain, but it seems that the maximum feeding value, of grain and straw together, is reached some time before the crop is dead ripe. The time to cut, where grain is the main object, is when the crop has changed to a yellow colour and about a week before it is absolutely ripe. The grain will then be able to mature in the stook and there is little risk of corn being lost in the harvesting operations. If cutting is delayed until the crop is dead ripe, shaking may cause heavy loss, especially with some varieties, before the grain is safely secured in the stacks. In this respect the crop is less suitable than the other cereals for combine-harvesting as it cannot be left long after binder ripeness, but in low-rainfall areas, although the risks are greater than with wheat or barley, combining is common. In cool and moist districts relatively early cutting is the rule, because the translocation of foodstuffs from the straw to the grain will go on in the stook; in dry, hot areas the plants shrivel very rapidly after cutting.

The oat crop is more liable to ferment and heat in the stack than are the other cereals, and great care should be taken to ensure that it is thoroughly dry before carrying operations are commenced. Before it is in a fit condition to lead, the crop should stand in the stook for about a fortnight, though winter oats, ripening in the hot weather of late July, may be ready in a week. The condition of the crop should be determined from time to time by examination of the juicy leaf insertions and the weeds in the base of the sheaves. Should rain, other than the slightest of showers, occur while the crop is being carried, it is advisable to discontinue the work until

the crop has dried. Less care need be taken, however, if very small stacks are being built, or if the stackyard is in a position well exposed to wind.

In the wetter and upland districts oat stacks are frequently built small—say six cartloads of sheaves, equivalent to perhaps 12 qrs. of grain—and they may be constructed round wooden tripods or hollow frames, which may communicate with the outside air by means of another frame placed in a horizontal position during the building operations. In this way cold air enters at the bottom of the stack and passes upwards and out through the sheaves, drying the corn and preventing heating. Another plan is to build the stacks small and over field or roadside walls, thus preventing undue consolidation and promoting aeration. In some districts the danger of overheating is so great that wire and timber drying racks, roofed with sheet iron, are erected, and into these the sheaves are packed and left until they are in a condition that allows them to be stacked with safety. Another way of securing the crop in a wet district is to build the sheaves into "huts" around metal tripods. These "huts" take the place of stooks in the field, but since they are very much larger the sheaves may best be brought to a given site by means of a sweep; they are built with three ventilating shafts to ensure aeration, and in them the crop is practically safe from the effects of bad weather. When a stack does over-heat it begins to lose shape and bend over towards its weakest side, and vapour may be seen issuing from its top. Such a state of affairs can only be corrected by pulling down the stack and re-setting the sheaves in stooks, or by rebuilding the contents into smaller ventilated stacks.

The stacks are thatched when they have settled, and threshing takes place from time to time throughout the season according to the requirements of the stock and the condition of the market. As threshed straw tends to go stale and is then less palatable, it is customary in some feeding districts to thresh weekly so as always to have fodder that cattle will eat with relish.

Yield.—The average weight of a bushel of oats is 42 lb., and the grain was formerly sold by the quarter of 336 lb. The average British yield is about 18½ cwt. of grain per acre; 24 cwt. might be considered a satisfactory crop on land of medium quality, and crops of 40 and even 50 cwt. are occasionally recorded. The yield of straw depends on the nature of the variety grown and on the rainfall. Grain-producing varieties when grown under

WHEAT

C

JULIANA ATLE

D

METEOR STARING

National Institute of Agricultural Botany

PLATE XXVI

BARLEY

PLUMAGE-ARCHER COMPTON

National Institute of Agricultural Botany

OATS

F.

Black Tartarian S.172

National Institute of Agricultural Botany

PLATE XXVI

OATS

G.

EAGLE

ONWARD

National Institute of Agricultural Botany

moderately moist conditions yield about 40 per cent. grain, or one and a half times as much straw as corn.

FUNGOID DISEASES

Smut.—Oats are attacked by two species of smut, one covered and the other loose, but in practice they are difficult to distinguish and their differences are unimportant.

When plants are affected by the disease the reproductive shoots issue from their sheaths covered with a mass of black fungus spores, though in other respects the plants appear to be perfectly healthy. The spores, which are those of the fungus feeding on the nutrients provided by the plant for the development of the grain, are carried by wind and rain to healthy grain and lie dormant until the following year. When the grain is sown they become active and produce a mycelium which enters the young plant, finds its way to the ear, and produces towards the end of the season a fresh crop of spores. Some crops contain a large proportion of these black heads, and the total loss due to the disease is very considerable.

Smut can be checked by treating the seed with a seed disinfectant, as for bunt in wheat.

Leaf-stripe.—This disease, which is sometimes called yellow leaf, appears to be widespread, and in some parts of the country it was formerly the most destructive disease affecting oats; it is worst on spring crops that have been sown early. The mycelium of the fungus is carried on the seed, and a striking feature of the disease is that, while affected seed may show a very high germination capacity in the laboratory, it fails to establish the expected number of plants in the field. An examination following on a partial failure reveals that much of the seed has germinated but that the shoots have wandered in the soil and have been unable to push above ground. The name *pre-emergence blight* is often used to describe this condition. Of the affected plants that succeed in breaking through and establishing themselves, quite a number show the first symptoms of "stripe," namely lightish spots on the leaves which gradually elongate until they form distinct yellowish or brownish stripes. Some plants succumb before reaching the 4-leaf stage. Later on, when the oats have reached the flowering stage, stripes may again be observed on the upper leaves.

A sure prevention for this disease is to treat the seed with a suitable organo-mercuric material, as for smut of oats and bunt

of wheat; and where this is done as a matter of routine the disease virtually disappears. Seed rates above 4 bushels ($1\frac{1}{2}$ cwt.) of treated seed are rarely required for a full stand.

Grey speck "disease" is due to manganese deficiency. It occurs mainly on soils of high organic matter content after excessive dressings of lime. Affected plants quickly recover if they are sprayed with an appropriate solution. This consists of 5 to 10 lb. of manganese sulphate, in 25 to 100 gals. of water per acre, with the addition of a wetting agent. If, as sometimes happens, the check to the crop has allowed a weed infestation to develop, spraying with a selective weed-killer may follow.

INSECTS AND OTHER PESTS

"**Leather Jackets.**"—These are the larval forms of species of crane-flies, popularly known as "daddy-long-legs." They attack all farm plants, but cause more apparent damage to oats taken after old grass than to any other crop. The adult flies appear from June to about the end of September and lay their eggs on grassland, preferring that which is rough and moist. The larvæ feed till the following spring before passing into the pupal stage, and during this time they not only attack plant roots but they come to the surface at nights and gnaw through the leaves and stems. The loss is usually most severe in a backward spring when the crop cannot grow away from the attack, and the damage may be accentuated by birds pulling the plants out of the ground in search of the larvæ.

When there is reason to expect grub attack a multi-tillering variety—*e.g.* Potato—should be grown for preference, because it will be better able to recover from the pest than one that tillers only slightly. Practical measures to combat the "leather jackets" are to stimulate the affected cereal with a top dressing of quick-acting nitrogenous manure, such as nitrate of soda, and to destroy the larvæ by means of poison.

To prepare poison bait for 1 acre, mix 1 lb. of Paris green with 30 lb. of bran or thirds and 2 gals. of water, to which a little treacle may be added. The material should be sufficiently moist to cause the poison to adhere, yet dry enough for convenience in sowing. The mixture should be broadcast over the affected crop, and it is found that the best results are got when this is done on a moist, warm night.

Frit Fly.—The larvæ of this fly cause damage to all cereal crops and grasses, but in this country the oat crop is the greatest sufferer. The frit-fly population seems to be subject to cyclical changes; a gradual rise occurs over several years, culminating in a few years of heavy damage, and is followed by a rather sharp fall and a few more years during which there is relatively little trouble. Early in the season the maggots do damage by feeding on the young plants inside the shoots; the upper leaves of injured shoots turn yellow and later wither away. A close inspection shows that the central shoots and one or two of the first tillers are yellow and badly developed, while a few of the youngest tillers and the outer leaves are healthy and green. The maggots, which are $\frac{1}{8}$ in. long, can be found in the hearts of the stunted stems, and a few pupæ may be found behind the outer leaf sheaths.

The first brood of flies appears in April and May, and egg-laying takes place shortly afterwards. The females prefer to lay on young plants—viz. those that have not passed the four-leaf stage—and will avoid crops that are strong and in a forward condition. It is advisable, therefore, in districts where the fly is a serious pest, to sow the oats early in March or even, in southern England, in the latter part of February, and to manure them liberally so that they may be strong and well established before the egg-laying season commences. Winter oats suffer much less from the spring attack than spring sown-crops.

A second generation of flies lay their eggs on the developing ears and the larvæ feed on the immature grain, causing considerable loss. A third generation lay eggs on grasses, particularly ryegrass, but the damage to the grass itself is inconsiderable. Serious damage may, however, occur in autumn-sown cereals following a ryegrass ley, the larvæ moving from the grass shoots, after ploughing has taken place, to the corn seedlings. Frit-fly attack is the cause of many failures of winter cereals following leys. The most certain preventive is to plough out the ley before August—*i.e.* before the egg-laying period of the third-generation flies.

The Stem Eelworm.—Nematode worms attack many field and garden plants, the chief farm crops affected being oats and potatoes. An oat plant parasitized by the eelworm suffers in much the same way as one attacked by frit fly, but if the stem base be examined it will be found to be swollen or "tulip rooted." As the worms are only $\frac{1}{25}$ in. in length their presence should be

confirmed by the use of a magnifying glass. Autumn sowing gives the pest more opportunity to cause damage. The old winter varieties, such as Grey Winter, are highly resistant, but some of the new sorts, especially S. 147, are rather susceptible. Eelworm and frit-fly attacks frequently occur simultaneously, and where the frit larvæ are discovered the other parasites are apt to be overlooked.

The only remedy is to encourage vigorous growth by nitrogenous top dressings, although the application of sulphate of potash is said to have a direct toxic action on the worms. The chief preventive measure is to allow longer intervals between successive crops of oats.

Cereal Root Eelworm.—This cyst-forming species can damage all cereals, but attacks are generally most severe in oats. The young stages attach themselves to the root system and later form cysts which can be seen with a strong hand lens. The life-history is similar to those of the potato and beet species.

Wireworm is dealt with under Wheat (p. 273).

BARLEY

Barley has been cultivated from time immemorial, and is believed to be derived from wild grasses native to northern Africa and western Asia. It is widely grown in all subtropical and temperate countries, and large areas are devoted to its cultivation in many parts of the British Isles. It is used for human food and is an important bread cereal in some parts of Europe. In this country barley flour is little used in normal times, but pot- and pearl-barley are in considerable demand for culinary purposes. An interesting feature in the composition of barley is the nature of its protein matter, which is quite different from the gluten of wheat and goes into solution when boiled in water; this extract, known as barley water, is largely used as a nitrogenous food for infants and invalids. For the feeding of farm stock, barley and its by-products have a very high value. The husk-content of the grain is much lower than that of oats, and this makes the cereal unsurpassed for the feeding of pigs; but it should always be crushed or soaked before use as it is extremely hard, and the animals are apt to swallow it without sufficient mastication. The straw is soft and friable and makes poor litter; it is usually cut when the grain is dead ripe and then contains little material of feeding value;

but if it is cut early it approaches oat straw in quality and is at all times superior to wheat straw for feeding purposes. All the best barley, however, is used for malting, and its degree of suitability for this purpose determines the market value of the crop, the straw being strictly a by-product.

Malting of Barley.—Barley is largely used for malting because of its high percentage of starch, and the object of the process is to bring about certain changes that enable the starch to be converted into sugar. When barley is placed in a suitable environment of air, moisture, and temperature, a number of ferments or enzymes are produced which convert the material of the endosperm into soluble substances suitable for transference to the embryo for the nourishment of the growing stem and roots. The chief enzyme produced is diastase, which converts starch into sugar, but protein- and cellulose-dissolving ferments are also formed. Maltsters take advantage of this natural process to obtain fermentable sugars from the contents of the grain. The first stage in the conversion of barley into malt is to soak the grain in water for two or three days, so that it may absorb enough moisture to activate its latent life; then it is spread out on the malting floor to encourage its germination. Its temperature is carefully controlled and it is turned over for aeration from time to time for about twelve days, by which time the rootlets have developed and the plumule has grown to about two-thirds of the length of the grain. The sprouted seeds are then removed to a kiln and thoroughly dried; they are then dressed to remove the dry rootlets, which are placed on the market under the name of malt coombs, and the finished malt is ready for marketing or storage.

When the malt is used for brewing it is crushed and mashed in water, when the ferment diastase once more becomes active and much of the remaining starch is brought into solution as sugar. The residue of the grain, consisting of the insoluble carbohydrate and protein materials, is removed and marketed under the name of brewers' wet grains, or, to reduce its weight and facilitate transportation, it may be desiccated and placed on the market as dry grains. A quarter of barley (448 lb.) will produce about 336 lb. of malt, which should yield 80 to 100 lb. of soluble material or brewers' extract.

Quality of Barley.—To judge the quality of barley for malting purposes the points to consider are those that indicate the greatest possible yield and the highest possible quality of extract

from a given weight of the grain. As the amount of the extract depends on the carbohydrate-content, and varies inversely with the proportion of oil and protein, the best samples possess a maximum of starchy material and show the least possible flintiness: the grain should be plump and the skin fine and wrinkled. Actually a nitrogen-content of above 1·6 per cent. (equivalent to 10 per cent. of protein) so detracts from the value of the grain that much barley is now bought subject to a nitrogen test. The colour of the barley is also important, as dark-coloured grains can be used only in the production of dark-coloured beers and stouts, while for pale ale a bright colour is necessary; and as light barleys are somewhat scarce they always command a higher price. Red ends to the grain indicate that the crop was cut before it was ripe. As barley has to be germinated and a solution of extract prepared from the malt, it is essential that it should be in a sound, mature condition, and it should be carefully prepared so that it contains no broken or damaged grains and no foreign matter. If the crop is severely treated in threshing, owing to the concave being set too close to the drum, the grains are frequently broken or skinned. Broken grains die and form a medium for mould growth, but they can be removed by modern machinery. Grain that is skinned or that has the skin loosened, however, is very objectionable, as these conditions lead to abnormal absorption of moisture during malting. The threshing, then, should be carefully performed and the grain well screened if it is to realize a good price. It is almost needless to state that any heating and weathering that detract from the appearance and odour of the sample will have a serious influence on the marketability of the crop. Barley varieties should be kept strictly pure, because in the malting process it is essential to have a uniform sample; it has been found that different sorts of barley do not germinate at the same rates and have to receive different treatments; mixed samples are difficult to malt and never produce satisfactory results.

From the farmer's point of view a variety must produce quantity as well as quality; but most of the best sorts in wide cultivation are not only capable of producing good yields but of bringing the highest awards at the brewers' exhibitions. It is a fallacy that quality can only be obtained when the crop is cultivated on impoverished soil that has a restricting action on the growth and yield.

In some of the recently introduced Scandinavian varieties, several of which outyield the standard native types, the quality, from the point of view of the British maltster, is less satisfactory.

Varieties of Barley.—The races of barley that are cultivated in this country are: (1) six-row barley; (2) bere or four-row barley; and (3) two-row barley.

The barley ear has three spikelets at each node and the groups of spikelets are arranged alternately on opposite sides of the rachis or main stem. In the six-row and four-row varieties all the spikelets produce grains. In the two-row varieties the central spikelet only produces a grain, the side florets producing only stamens.

It is probable that the six-row race of barley is a very ancient one. In our older varieties the straw is short and strong and the ears are very compact; the grain is irregularly shaped, poorly filled, and, when grown in our climate, poor in colour, and generally unsatisfactory for brewing purposes. The race is extremely hardy and is sometimes grown as a catch crop, being sown in autumn and cut for soiling purposes in spring, or it may be folded for stock. On dry chalky soils it is sometimes grown as the chief cereal for feeding purposes, taking the place of oats. Most of the barley that is imported, whether for feeding or malting, from California, North Africa, and Persia, belongs to the six-row type. *Prefect*, a six-row variety bred by Dr Bell at Cambridge, and introduced in 1944, has not been widely adopted. It stands well and resembles most six-row varieties in having fewer ears per plant than is the case with two-row barleys, but it has a greater number of grains per head.

Bere or four-row barley has all the florets fertile but only two regular rows of grains, the remaining four rows being irregularly placed on the lax ear in such a way as to give it the appearance of having four rows only. The race is still cultivated under the severe climatic conditions of north-west Scotland and northern Europe. The grain has the inferior malting qualities of the six-row type; it is used as a food for stock and to some extent in the manufacture of alcohol, but it is not good enough for brewing. Bere may be autumn-sown and used as a catch-crop for spring fodder, either alone or in a mixture with other autumn-sown species.

The two-row barleys are by far the most widely cultivated in Britain, and are the sorts used in the best barley-growing districts for the production of grain of the finest malting quality. There

are many different varieties of two-row barleys, but the following are the more important:—

Pioneer, also a product of the Cambridge Plant Breeding Station, is the only true winter variety that is widely grown. It is lax-eared, resembling Spratt-Archer (see below). In winter it has the prostrate habit typical of winter corn.

The remaining two-row varieties properly belong to the spring group, but several of these may be sown, in certain parts of eastern and south-eastern England, in winter. That most commonly grown in this way is Plumage-Archer.

Plumage-Archer has erect, rather dense, broad ears, and a very short "neck" which does not "kink." The straw is short and stands well. It ripens comparatively early, but, like all barleys intended for malting, should not be cut until it is fully ripe. It gives excellent yields on fertile soils, and the grain, which is large, plump, regular, and of a pale yellow colour, is unsurpassed for malting quality.

Spratt-Archer has drooping, long, rather lax, narrow ears, and a short "neck." An important character is the freedom with which it tillers. The straw is much the same length as that of Plumage-Archer, and stands very well. It ripens a day or two later than Plumage-Archer, and usually gives slightly heavier yields. The grain is of excellent malting quality.

These two varieties are well established in this country, and both can be relied upon to satisfy the requirements of the farmer and the maltster alike. There is some evidence, however, that Spratt-Archer is better suited to lighter classes of barley soils, and Plumage-Archer to richer soils, especially in districts with an ample rainfall.

Earl is almost indistinguishable from Spratt-Archer except that it ripens seven to ten days earlier, which is an important advantage in some areas.

With the higher levels of fertilizer usage that have lately been adopted, the farmer's chief objection to *Spratt-Archer* and *Plumage-Archer* has been their liability to lodge. Where this risk is considerable the tendency has been to prefer one or other of the Scandinavian varieties, *Kenia* and *Maja*, introduced in the thirties, which usually, under conditions of high fertility, outyield the older English varieties. Since then there have been further introductions from both Denmark and Sweden, notably *Carlsberg*, *Herta*, and *Freja*. These last are short- or strong-

strawed, but of rather inferior malting quality. Most are earlier-ripening than *Spratt-Archer*.

Plant breeders have for some years been attempting to combine the yield and field characteristics of the Scandinavian types with the malting quality of the English. The most successful to date is *Proctor* (Cambridge), released in 1953.

CULTIVATION OF BARLEY

Soil and Climate.—Barley can be grown under almost any conditions of soil and climate, the only frequent cause of failure being soil acidity; but all conditions do not give equally good barley for malting purposes. In Britain, where barley is grown primarily for sale to maltsters, the crop is cultivated most largely in the better parts of the country, and the finest samples are obtained from a limited number of districts. Probably our best barley is grown in Norfolk, Suffolk, and Cambridgeshire, but there are a number of belts in different parts, mostly bordering on the sea coast, that give almost equal results in yield and quality. Of these the best known are Fife, East Lothian, and Berwickshire in Scotland, and, in England, East Yorks, Lincolnshire, the southern chalk belt, and Taunton Vale in Somerset. In Britain, then, the barley districts are the eastern and southern counties, which are the regions of maximum sunshine and moderate rainfall. Considering the temperature of these districts during the growing season, it is found that where the rainfall is almost constant, as along the east coast, the cooler the temperature the greater the yield. Although the barley districts are relatively dry, the biggest yields are obtained when the rainfall is above average, but not excessive; in very wet seasons the yield is reduced, and rain during ripening and harvest time injures the quality. A high rainfall in June, followed by a dry July and August, produces excellent results; but if sowing is delayed by wet weather both yield and quality will suffer, for late sowing brings about an increase in the nitrogen-content of the grain. Seasons that are hot and dry throughout produce pinched, hard, and inferior samples. The best soils are light calcareous loams, and no great depth is required. These may be naturally poor, provided that fertilizers are used generously. In past times the chief means to the maintenance of the fertility of typical barley land was the folding of sheep receiving oilcake or other high-protein

concentrate. With the decline of sheep-folding, barley growers now rely mainly on fertilizers. In East Anglia, however, where barley and sugar-beet are now the main light-land crops, the sugar-beet tops, either folded off or ploughed in, play a part of some importance. The type of light gravelly soil that "burns" is unsatisfactory, since prematurely ripened grain is unsuitable for malting. Probably the best barley is grown on the Chalk, Tertiary, and Recent deposits, and it is seldom that a good sample is obtained from heavy or high-conditioned soil that is suitable for wheat, or from peaty soil. In dry seasons, however, good yields and good samples are obtained from medium and strong loams. It is essential that the soil should not be acid, otherwise barley will not thrive; indeed, it may die out entirely.

Place in Rotation.—On the lightest soils, barley commonly follows roots, kale, etc., but on heavier land it usually succeeds a cereal, normally wheat. On thin, light soil sheep-folding leaves the upper layer impregnated with manure, consolidated by the treading of the animals, and in excellent condition for the cereal crop that is to follow. In good districts where the land is in high condition the feeding-off of a root crop is likely to leave the soil too rich, when the succeeding barley will be liable to lodge, and the grain will be nitrogenous and dark in colour. If barley has to be grown under these conditions a strong-strawed variety should be selected.

Probably the finest samples of barley are grown not after roots but after another straw crop. In this way the first crop removes the excessive richness, and the barley, feeding upon a controlled quantity of soil nitrates, tends to be of a more starchy nature and of better colour; the sample is also more even because the inequalities of manuring produced by the sheep feeding are mostly removed by the first crop. With efficient weed control and with adequate dressings of properly balanced fertilizers, several successive crops of barley can be grown with success.

Preparation and Seeding.—The nature of the preparation depends on the condition of the soil; but on land that tends to become poached by the treading of sheep or the carting of roots it is desirable to plough early, so that the furrows are exposed to frost and thaw and the detrimental effect of the puddling is removed. On light land, where the texture is not injured by sheep, ploughing can be performed any time before it is necessary to prepare the ground for sowing. Barley is generally believed

to do best on a very fine and moderately deep seed-bed, and this should be prepared by dragging, harrowing, and rolling as often as is necessary. It is in the driest areas that the greatest attention must be given to seed-bed preparation. A rough tilth or an uneven depth of sowing may result in delayed germination of some of the seed, and the resulting crop, containing a proportion of unripe ears, will yield an unsatisfactory sample for malting. On light land in dry areas excessive or ill-timed cultivation may lead to drying out of the seed-bed with the consequence of patchy germination. The grain is drilled at the rate of 1 to 1½ cwt. (2 to 3 bushels) per acre in England, and 1¼ to 2 cwt. (2½ to 4 bushels) in Scotland. The drills should not be more than 7 in. apart, otherwise there is a risk of an increase in the nitrogen-content of the crop. When the drilling is completed the field is given a harrowing and finally rolled.

Barley has a shorter period of growth than the other cereals, and in a late season crops can be obtained from seed put in as late as May. Nevertheless the best crops and the finest samples are got when seeding takes place in early March, or even in February in coastal areas where there is little risk of frost damage; indeed, it is best to sow as soon as a satisfactory tilth can be secured, provided there is no risk of the growth being subsequently checked by severe frost. When winter barley is grown, it is sown in the same manner as wheat. In parts of East Anglia many farmers sow part of their barley area with ordinary two-rowed varieties, such as Plumage-Archer, in October or November; in parts of Kent the latter part of December is preferred. If the winter turns out to be severe, the plants may not survive, but in a normal season they do well and produce an early crop, usually of excellent quality. Naturally the practice is confined to the fairly light and freely drained soils.

Manuring.—When barley is grown on land in high condition, or on land where a root crop has been consumed, it is not as a rule necessary to supply any artificial fertilizers; but under conditions where the land is so rich that luxuriant vegetation and late ripening may endanger the quality of the crop, it may be desirable to apply 2 or even 3 cwt. superphosphate per acre and to balance this with an appropriate amount of potash. As in the case of other British crops, the heavier applications of superphosphate are more likely to be needed in the north and the wetter west. At the other extreme, in the dry south and east, it may not pay

to use more than 1 cwt. of the fertilizer. Again, when barley is grown after another white crop, or on soil of low fertility, it may be worth using these quantities of mineral fertilizers with the addition of 1½ or 2 cwt. of sulphate of ammonia per acre. The rate of nitrogen application must be decided in relation to the strength of stems of the variety: thus Herta or Proctor will bear more generous treatment than Spratt-Archer. Under most conditions where the soil is of average fertility, it pays to manure barley with about 1 cwt. of sulphate of ammonia per acre. On medium loams that are in good heart the application of potash and phosphate may make but little difference to the yield; but potash may improve the plumpness of the grain and phosphate tends to promote even and early ripening. Many thin and light soils, which produce barley of high quality, are naturally deficient in potash. Moreover both potash and phosphate may be required by grass and clover which are to be sown under the barley. The nitrogen-content of the grain is not increased by a moderate dressing of nitrogen—say 1½ or even 2 cwt. of sulphate of ammonia—applied up to the time the tillers become vertical; indeed where this produces a marked increase in the yield it may actually decrease the proportion of nitrogen in the grain—but heavy nitrogenous manuring, particularly at a late stage of growth, does have an injurious effect on quality. Fertilizer is often applied by the combine drill, but under dry conditions the amount of water-soluble potash and nitrogen must be limited, since an excessive concentration in the soil solution may impede germination. No more than the equivalent of ⅔ cwt. of sulphate of potash and 1¼ cwt. of ammonium sulphate should be used. If a typical N.P.K. compound is used, the dressing should not exceed 3 or 3½ cwt. per acre. Farmyard manure is unsuitable for barley because of its high content of nitrogen and the difficulty in securing its uniform distribution.

After-cultivation.—The cultivations carried out between seeding and harvesting barley are very similar to those for the other cereals. The land is usually rolled when the plants are a few inches high, and a harrowing may be given to suppress annual weeds. Spraying for weed control, if necessary, should be done after tillering is complete and when the main stem has four or five leaves. Weed competition can seriously affect both yield and quality.

Harvesting.—Barley is allowed to become dead ripe before

it is cut. When this state of maturity has been reached, the ears are bent over, the individual grains are hard, with pale yellow wrinkled skins, and the straw is practically dry. If the crop is cut too soon an uneven sample results, and the maltster is unable to obtain that uniformity of germination so necessary to the production of high-class malt. At one time much barley was cut with a scythe or mower and "made" in the same way as hay. It was exposed in the swath and turned from time to time so as to benefit by the bleaching action of the sun, and finally carried and stacked in the loose state. But while this treatment produced grain of excellent quality, the cost is usually too high for modern conditions. With the advent of the binder and the rise in cost of labour, the crop began to be cut and bound in the usual way, with no serious detriment to the quality. Direct threshing by "combine" eliminates the risk of sprouting or discoloration in the stook, but there is rather more risk of loss of ears in the field. Close control of temperature is necessary in the artificial drying of barleys for malting. In the early days of combining many samples were seriously damaged through the use of poor types of tray driers which did not permit of proper temperature control. With a modern flow drier and strict adherence to the maximum temperature indicated by the table on page 215, no damage whatever need occur.

With good weather the crop is generally ready for carting out of the shock in about a week, but during periods of wet weather carting is greatly delayed. The straw is of a soft nature and holds rain readily, and the grain, which is unprotected by chaff, becomes dark coloured and poor in appearance. When the crop has been used to nurse clover seeds the bottoms of the sheaves frequently contain an abundance of soft green herbage, and the drying period in the stook is thus greatly prolonged.

Barley is stacked in the usual way, and if it is secured in a dry, sound condition its colour generally improves very considerably before threshing takes place. If, however, the corn is badly secured or in a wet condition, it changes in the stack to a dark inferior colour and in bad cases becomes mouldy. It seldom comes out of the stack having the same quality as when it was put in: it either improves or deteriorates.

Yield.—The weight of a bushel of barley varies a great deal. A good sample should weigh 56 lb., although prize-winning barleys are heavier. The bushel weight is indicative of the

plumpness and fullness of the grains, light weights being got when these are thin and contain a high proportion of husk. The average yield is about 20 cwt. (5 qrs. of 448 lb.) to the acre, and about the same weight of straw—that is, 50 per cent. grain and 50 per cent. roughage. The yield of grain may often reach or exceed 30 cwt. under good conditions, and crops of 40 cwt. and more have been recorded. The British average yield is second only to that of Denmark.

FUNGOID DISEASES

Covered Smut.—Barley suffers from the attacks of a fungus causing a loose smut which is very similar to loose smut of oats (except that it cannot be cured by disinfecting the grain), but it is much more commonly attacked by covered smut. In this disease the ears issuing from their sheaths are not covered with sooty powder, but the grains, though held together by the skin, contain a mass of black spores enclosed by the thin adherent chaff. The grains remain whole until threshing takes place, when the concussion breaks them up and the spores are liberated. Not only do the spores infest healthy barley grains, but they discolour the whole sample and reduce the market value of the crop.

The transmission of covered smut to the next crop can be prevented by dressing with a seed disinfectant, as in the treatment of wheat for the prevention of bunt.

Leaf-stripe.—This disease, produced by the attack of *Helminthosporium gramineum*, causes the leaves of the young plants to wither and die off, and an examination reveals longitudinal dark-coloured stripes on the laminæ. Affected plants produce blind ears and the loss is therefore much greater than is occasioned by the reduced assimilating surface. Another species, known as *Helminthosporium teres*, produces spots on the leaves, the condition being known as net blotch; the disease does not occur regularly throughout the crop, but in isolated patches; it does not, however, cause blindness.

Leaf-stripe can be controlled by the mercuric dust methods of seed disinfection already described.

INSECT PESTS

The Gout Fly (Ribbon-footed Corn Fly) is a pest that causes considerable damage to barley and also to wheat. The flies lay their eggs on the plants, and when the larvæ hatch

out they eat their way into the stem below the ear while it is enshrouded by its surrounding leaves. They eat a groove down the axis to the first node, which is so characteristic that it is quite sufficient to confirm the nature of the attack. The plants become stunted and "gouted" in appearance and fail to produce grain.

As egg-laying takes place in May and June, and again in September, either autumn- or spring-sown plants may be attacked. In districts where the fly is troublesome it is therefore advisable to sow winter wheat and barley late, and the spring crops should be put in early so that they will be well established before egg-laying commences. If a crop is obviously suffering badly from an attack it may be stimulated into producing a certain amount of grain, which may pay for the labour of harvesting, by giving it a quick-acting nitrogenous dressing; but where the ears are practically all grainless it should be fed off by sheep.

RYE

It is probable that our cultivated varieties of rye were obtained originally from a wild perennial species found in eastern Europe and Asia Minor. Rye is largely used as a bread cereal in Germany and Russia, and resembles wheat in having grain easily separated from the chaff in threshing, and in yielding corresponding offals on milling. In this country it is cultivated as a forage crop, but more largely for its grain and straw. Rye straw is longer, stronger, and wears better than the straw of wheat. It is therefore valued for thatching, packing, etc.

Varieties.—Until the introduction of new and more productive varieties from Scandinavia, the native English rye was generally grown, whether for grain or for green forage. The native type may be sown either in autumn or in spring, whereas the Scandinavian types listed below are all true winter types and will not come to ear fully if spring-sown. The native types produce more leafage than any of the Scandinavian varieties and are therefore to be preferred for forage cropping. The yield of grain, however, is relatively low.

The short-strawed Scandinavian varieties, King II, Pearl, and Petkus, are far superior in grain yield to the English type. King II (Svalof) is the most popular.

CULTIVATION OF RYE

Soil and Climate.—Rye is a drought-resistant plant which thrives under a great variety of conditions; it is productive upon almost any class of soil and very resistant to acid conditions. When grown for grain on good soil it is usually less profitable than the other cereals, and its cultivation is therefore confined to districts of poor, dry, light land that produce inferior wheat and oats. It also succeeds on peaty soils and on the poorer sorts of black fen. This does not mean that rye does best on poor soils: it does best on good loams, which, however, yield more profit under other crops. It has the additional advantages that in late districts it enables an early start to be made with the harvest, and that it is considerably more winter-hardy than wheat. When rye is grown on good land it is mostly cultivated for forage purposes, and it is, on account of its earliness, extremely valuable for feeding-off or for soiling. The plant, however, must be consumed at the right stage, for it very soon becomes fibrous and unpalatable.

Place in Rotation.—When rye is grown for seed it takes the place of any of the other cereals in the rotation, and is usually taken after roots or clover. When grown as a catch crop, as it often is, it frequently follows another white crop, is sown in the autumn for feeding-off in the spring, and may be followed by roots or kale.

Preparation and Sowing.—The seed-bed is prepared as for wheat, and the grain may either be broadcast or drilled in the usual way. From 1 to 1½ cwt. (say 2 to 3 bushels) is required to sow an acre, and seeding should take place from two to three weeks before wheat sowing commences.

Manuring.—The old native types of rye are rather unresponsive to fertilizers and prone to lodge; but the new varieties may be treated about as generously as oats without risk of lodging. King II has been shown to respond well to spring applications of nitrogen, and quantities up to 3 cwt. per acre of ammonium sulphate have been used with profit.

Harvesting.—Cutting takes place about a fortnight before wheat harvest commences, which is about the beginning of August in medium early districts. The crop is bound and stooked in the usual way and, as the straw contains very little sap, carrying can take place a week or so after cutting. When high-quality rye straw is required for special purposes it may be cut before the ear has

filled, then dried and used: this avoids the threshing process which damages the stems considerably. Where it is grown as a forage crop it must be cut early—before it shoots—as towards the end of its growing period it becomes hard, dry, and unpalatable.

Yield.—The average weight of a bushel of rye is about 58 lb., but much depends on the variety, the winter sorts weighing up better. Common yields are 16 to 20 cwt. (4 to 5 qrs.) of grain and 30 cwt. to 2 tons of straw per acre. Yields of grain up to 25 or 30 cwt. have been recorded.

DREDGE CORN

The term *dredge corn* is sometimes applied to mixtures of cereals and pulse crops—*e.g.* oats with beans, peas, or vetches or all three (see p. 394). It is also used for a mixture of oats and barley, which is common in Cornwall and occasionally grown elsewhere. It is cultivated for the production of feed corn and on average may produce a rather higher yield, from a given acreage, than would be obtained from the two species cultivated separately. Care is necessary in the choice of varieties so that the two components may ripen together.

The corn is sown at the usual time for spring cereals, at the average rate of 4 bushels per acre, the proportion of oats being half, two-thirds, or three-quarters according to the local soil and climatic conditions and the use to which the crop is to be put. It is manured and harvested like other cereals. A satisfactory yield is about a ton of grain per acre.

LODGING IN CEREALS

All cereals and hay crops are subject to lodging. Apart from the attack of the eye-spot fungus, which has already been discussed (p. 273), lodging may be caused by over-luxuriant or ill-balanced development, by rainstorms, or by a combination of those causes. The effect of lodging on the yield and quality of the crop depends on the stage of development at which it occurs. Rain and wind may cause a winter-proud crop to lodge when the straw is still growing and is therefore still capable, by bending at the nodes, of restoring the ears to an upright position, and in such a case there is no serious damage. Lodging at a later stage, when the straw has lost its power of growth, has much more serious

results, because the ears do not mature satisfactorily when lying on the ground, and even if the crop can be harvested, there is a loss of yield and a high proportion of shrunken grains; moreover the condition is often rendered worse by the development of second growth—that is, by the growth of new shoots from the bases of the fallen stems. Lodging at the end of the season when the grain is almost full and mature may have little if any effect on the yield; indeed the lodged crops often outyield the standing crops in the same district, but the subsequent difficulties in harvesting may adversely affect the quality of the grain.

Lodging is generally caused by wind and rain, and the varieties most affected are those which are characteristically weak in the straw—usually because the diameter of the culm is small in proportion to its length—or are lacking in root development. In the former case knuckling over generally occurs at the lower internodes; in the latter the plant may be partly uprooted so that it topples over at the ground. Certain fungi attack the base of the stems and make them unable to bear the weight of the ears. Again, repeated pressure of the elements may bend the straw right over without any breakage taking place.

The use of too much seed on rich land may cause lodging. In this case the lower parts of the plants are so dense and shaded that they become drawn and weakened and unable to withstand wind and rain or support a heavy ear. It is noteworthy that excessive seeding may be due to the use of small-sized seed at normal sowing rates. On rich land it is helpful to adopt wider spacing between the rows of grain.

Poverty of a particular nutrient may weaken the plants and produce lodging, but there is no evidence that the straw is strengthened by applications of potash and phosphate in addition to what is required to make a balanced fertilizer. A reasonable amount of nitrogen fertilizer, by promoting the vigour and well-being of the plant, will reduce the risk of lodging, and it is only where excessive amounts of nitrogen are used that the straw is weakened, ripening is delayed and liability to lodging is increased. Of course even strong-strawed cereals, seeded correctly and given mineral manures, are likely to go down when grown after clover-rich old pastures in a wet year. Obviously the need here is to grow not cereals but potatoes, roots, or kale in the first season.

When a cereal crop has "swung" it can generally be harvested with a binder cutting one way; but if the condition is rather bad,

corn lifters may have to be fitted to the cutter bar. The combine harvester, fitted with a special pick-up mechanism, can harvest crops that are beyond the capacity of the binder. When too badly laid for machine cutting, the harvesting may be carried out with the scythe, which is handy for dealing with patches of corn that are lodged in all directions. For the worst cases, where straw and ears are practically flat on the ground, the reaping hook has the advantage of enabling the straw to be eased or pulled up with the point before it is cut with the blade. But under present conditions, wherever the acreage of cereals is large in relation to the numbers of workers, it is seldom possible to do much harvesting by hand.

CHAPTER III

THE POTATO

THE potato (*Solanum tuberosum*) was introduced from South America in the sixteenth century, but in those early days it was regarded rather as a curiosity than as an article of commerce, and it was not until about two centuries later that it was cultivated to any extent on a field scale.

As a producer of human food the potato is the most valuable crop grown in this country; it is cheap, and its dietetic value is considerably higher than was for a long time supposed. As a food for stock, especially pigs, it is very valuable and gives a high production in terms of energy per acre—about twice as much as a cereal. In this country, however, only diseased or damaged or unmarketable potatoes are used for stock feeding in substantial amounts. Boiled potatoes will develop acidity and ensile quite satisfactorily if they are packed tightly in a pit, tank, or other suitable container. The silage can be used for pigs and poultry when fresh potatoes are not available.

The potato crop has, however, a number of disadvantages. Its bulky nature makes it costly to market, and for this reason, even where the soil is suitable, large-scale production tends to concentrate in areas not too far from cities. Again, even where a ready market is at hand, the large number of workers required for timely planting and harvesting restricts cultivation (on a large scale) to districts where casual labour is available. Mechanical planters are now satisfactory under many sets of circumstances, and it may be that efficient mechanical harvesters will be devised. The crop was formerly very speculative, the yield being variable and the demand very inelastic, so that in years of high yield the market was glutted and prices fell to an unprofitable level. An assured market for sound ware is provided by the Potato Marketing Board, though the grower cannot always sell at the time of his choice.

Quality of Potatoes.—The farmer, of course, requires a variety that will produce the greatest possible yield per acre, but he must also consider the buyer's point of view or his crop will not meet with a ready sale. Apart from yield, the most important

points are keeping quality and resistance to disease. Potatoes have to be stored for considerable periods, and it is disastrous if a large proportion decays or deteriorates in the clamp, as a good crop may in this way be reduced to an inferior one, and the expense of picking over diseased tubers is extremely heavy. Not only should the variety be capable of resisting disease and decay in the pit, but it should withstand the effects of the many and serious pests that beset it in the field, the most devastating of which are blight, wart disease, and the virus or "degeneration" diseases. No varieties yet in general cultivation are immune from blight, though many are resistant in greater or less degree. Attempts are being made by hybridization with certain wild species of *Solanum* to create commercial varieties with immunity to all the common strains of the fungus. As regards Wart disease, it is fortunate that many completely immune varieties have been produced, so that it is possible to grow healthy crops on land that is heavily infested with the disease. For general economy it is also advisable to obtain varieties that develop their tubers at a suitable depth below the surface; if they protrude above the soil they become greened by the light and are then difficult to sell, while if too deep they are difficult to get out with an ordinary potato digger and, apart from the numbers that are sliced and damaged, many may be left in the ground to become a source of trouble in the following crops. The potato is the principal cleaning crop in the rotation of many farms, and a variety that develops a large amount of surface growth and leafage is most efficient as a smotherer of weeds, and most likely to leave the soil in a clean condition. There are varieties that cannot be cut for seed as they do not grow well from cut sets, while at the other extreme there are potatoes that give excellent yields when cut to a single "eye."

From the point of view of the consumer the cooking quality of the variety is most important. In England, white-fleshed sorts that become "mealy" on boiling are generally the most popular for the ordinary domestic trade. On the Continent yellow-fleshed potatoes possessing a waxy texture are preferred. Varieties that produce either very large or very small tubers are not in demand, and varieties that are irregular in shape or deep in the eye, and are consequently difficult to peel without occasioning considerable loss, are never popular. The colour of the skin varies through a wide range—purple, red, pink, red-eyed, russet, and white all

being common, but colour does not matter much when the other qualities of the variety are satisfactory. The shape may be round, oval, or kidney, but this is of little importance in the domestic trade provided the tubers are regular. For the chipping trade, which absorbs an enormous tonnage, the potato should make a firm chip that turns golden brown on frying and stays firm. As a rule the best boiling varieties are also the best for frying and absorb least fat. The potatoes should also be without sunken eyes and of regular shape—preferably round—so that they can be dealt with efficiently by peeling machines. Blemished tubers that require hand trimming are greatly disliked.

Apart from varietal differences, eating quality appears to be determined more by the soil and climate than by manuring. Quality is best in dry districts and in dry years, dryness and warmth having the most beneficial effect towards the end of the growing season. For good quality the potatoes must be fully mature, and poor quality results when the growing season is interrupted by blight or early frost. Loam and light soils give better quality than those that are heavy or peaty. The quality after corn is likely to be better than after newly ploughed ley.

Varieties.—An enormous number of different kinds of potatoes are now on the market. In years past potato varieties tended to be rather short-lived, but many sorts popular to-day—Majestic and King Edward, for example—have been in cultivation for many decades. One reason is that new varieties have been subjected to increasingly severe tests and another is that certification schemes for seed crops do much to control virus infection. A variety consists, strictly speaking, of a great number of parts of the same individual mother plant, and the old view was that degeneration was the inevitable consequence of the old age of this plant or, in other words, the result of continued vegetative reproduction. It is, however, now certain that "degeneration" is, in the main, not a loss of constitutional vigour but is due to the accumulation in the stock of virus diseases (see p. 344). Careful search has disclosed fully healthy plants of quite old varieties, and considerable stocks have been built up from these. There is no reason to believe that these selected stocks are less vigorous than the original plants.

When new varieties are being raised the chief objects kept in view are the production of a good yield, resistance or immunity

to disease, good shape and colour with good keeping and cooking qualities. The commonest way to raise new sorts is to sow the seed from a self-set potato berry. In the case of organised plant breeding, crosses are made between selected parents by emasculating the plant on which the berries are to be grown and impregnating the stigmatic surface with pollen from the other parent. When the berry has matured, the seeds, which may number two or three hundred, are sown. The seedlings which develop exhibit many forms and characters differing from the parent types. The great majority are as a rule inferior or unsuitable: some develop long stolons and few tubers; most are poor croppers and many are quite useless because of their irregular shape and unattractive appearance; only a few are of sufficient merit to justify their propagation until they can be given a fair trial on a field scale. A number of experimenters are using certain wild species of potatoes for crossing purposes, with the object of imparting hardiness and disease-resisting capacity to our cultivated sorts, and it is likely that a much wider range of varieties will become available in the future.

The different varieties of potatoes are generally classified according to their earliness. There is a gradation from the extreme early sorts to the very late maincrops, but (although there are no real dividing lines) potatoes are classed as Earlies, Second Earlies, and Maincrops. Sometimes the terms Early Maincrop, Early Second Early, etc., are also used.

The comparative popularity of the numerous varieties under cultivation can perhaps best be deduced from the accompanying table on page 312. The following descriptive list includes those most widely cultivated at the time of writing and also the newer varieties showing promise of general usefulness.

The descriptions of the morphological characters of the varieties are taken, with the permission of the Controller of H.M. Stationery Office, from *Seed Potatoes*, issued by the Department of Agriculture for Scotland and from current lists published by the N.I.A.B.

Early and Second Early Varieties.—*Epicure.*—Tuber: round, irregular; skin white, but turning pink on exposure; eyes deep, ridged, with raised eyebrows; flesh white; sprouts pink.

Flower: white, not blooming freely; buds dark with green tips.

Approximate Acreage of Principal Varieties of Potatoes in England, Wales, and Scotland, 1952

Variety	Acres, England and Wales	Per-centage Total, England and Wales	Acres, Scotland	Acres, Total	Per-centage Total for Group	Variety as Per-centage Total Potatoes
First Earlies—						
*Arran Pilot .	61,000	49	8,100	69,100	44	8
*Home Guard .	33,400	27	7,400	40,800	26	5
*Ulster Chieftain	9,300	7	300	9,600	6	1
Duke of York .	4,250	3	1,350	5,600	4	
Ninetyfold .	4,450	4	150	4,600	3	2
Eclipse . .	4,000	3	1,200	5,200	3	
Epicure . .	3,600	3	11,600	15,200	10	2
Sharpe's Express	1,600	1	850	2,450	1	...
Others . .	3,400	3	750	4,150	3	...
Total .	125,000	100	31,700	156,700	100	18
Second Earlies—						
*Great Scot .	3,200	32	2,600	5,800	34	1
*Ulster Ensign .	2,100	21	100	2,200	13	
*Craig's Royal .	1,600	16	1,400	3,000	18	
*Dunbar Rover .	900	9	450	1,350	8	
Royal Kidney .	270	5	880	1,150	6	1
British Queen .	270		830	1,100	6	
*Catriona . .	170	2	180	350	2	
Others . .	1,490	15	660	2,150	13	
Total .	10,000	100	7,100	17,100	100	2
Maincrops—						
*Majestic . .	286,800	50	37,800	324,600	45	36
King Edward .	102,500	18	13,200	115,700	16	13
Red King .	17,000	3	2,300	19,300	3	2
*Arran Peak .	36,300	6	1,900	38,200	5	4
*Arran Banner .	32,200	6	4,200	36,400	5	4
*Redskin . .	25,500	5	25,300	50,800	7	6
*Gladstone .	15,600	3	2,000	17,600	2	2
*Doon Star .	8,100	1	1,600	9,700	1	1
*Dr MacIntosh .	6,100	1	1,500	7,600	1	1
*Craig's Defiance	4,900	1	500	5,400	1	1
*Kerr's Pink .	3,200	1	46,000	49,200	7	5
*Arran Consul .	3,500	1	750	4,250	1	
*Dunbar Standard	2,700		400	3,100		
*Record . .	2,700		700	3,400		
*Stormont Dawn	1,850		50	1,900	2	2
Arran Chief .	1,200	2	800	2,000		
*Arran Victory .	1,200		400	1,600		
Up to Date .	700		2,300	3,000		
*Golden Wonder	170		5,500	5,670	1	1
Others . .	13,780	2	5,800	19,580	3	2
Total .	566,000	100	153,000	719,000	100	80

Immune from wart disease.

Summary of Acreages of Groups

	England and Wales	Scotland	Total	Percentage
First Earlies . .	125,000	31,700	156,700	18
Second Earlies . .	10,000	7,100	17,100	2
Maincrop . .	566,000	153,000	719,000	80
Total .	701,000	191,800	892,800	100

This variety is not immune from wart disease [1]; it is susceptible to blackleg, leaf roll, and virus Y, and its tubers are very susceptible to blight. It is "field immune" [2] from viruses A and X so that, as virus Y is relatively uncommon, the stocks seldom suffer from mosaic. Bolters occur. Strictly speaking, Epicure is a second early, but it bulks so early that when lifted in an immature state its yield compares favourably with that of any other popular first early. The plants recover well if damaged by frost, and it is the most popular potato for the early districts in Scotland. The eating quality is poor at the normal time of lifting, but is quite good if the potatoes are left to mature; the deep eyes are rather objectionable.

Arran Pilot [3] is earlier in bulking than most early varieties, though variations in type of haulm, associated with earliness of tuber production, exist in this variety. Considerable losses of seed occur owing to dry rot. Special care must be taken to use healthy seed of a good stock. When allowed to mature fully, this variety produces very heavy crops of shapely tubers which are, however, rather variable in size. Cracking or second growth of the tubers is rare in this variety. The tubers are thick kidney in shape, the skin and flesh white, and the eyes shallow.

Home Guard [3] does not bulk so early as good stocks of Arran Pilot and under average conditions produces a lower yield whether lifted green or at full maturity. Type of haulm is more constant than with Arran Pilot, and losses from dry rot are less frequent. Home Guard is prone to early sprouting, and care should be

[1] The diseases mentioned in these descriptions, and the fungi and viruses causing them, are described on the pages commencing at page 340.

[2] Field immunity arises from the fact that invasion of the plant by the virus leads to the death of the affected tissues. Usually the infection is local and only the infected portion dies. In any case the virus cannot spread in a field-immune variety.

[3] Immune from wart disease.

exercised in the management of seed before planting. Home Guard suffers more severely than other early varieties from the effects of drought. At full maturity, which is distinctly earlier than that of Arran Pilot, cracking or second growth of tubers is uncommon. The tubers are oval in shape and uniform in size, the skin and flesh are white, and the eyes shallow.

Ulster Chieftain [1] bulks, if anything, earlier than Arran Pilot under favourable conditions. The type of haulm is low growing and compact and fairly constant. The amount of cover produced is less than with most other early varieties. The variety responds well to good cultivation. Loss due to dry rot occurs, but is not so serious as with Arran Pilot. Ulster Chieftain matures earlier than Home Guard and Arran Pilot. At full maturity, coarseness of tubers may occur and yields are lower than those of Arran Pilot or Home Guard. The tubers are oval in shape, the skin and flesh are white, and the eyes shallow. A feature of Ulster Chieftain is the uniformity of tuber size.

Ulster Premier [1] does not bulk as rapidly as Ulster Chieftain or Arran Pilot. The haulm is of medium height and spreading, with glossy leaves and white flowers. Type is fairly constant. Losses of seed occur through dry rot, and in this respect Ulster Premier is similar to Arran Pilot. Cropping capacity is similar to Home Guard, to which it corresponds in maturity. The tubers are kidney-shaped, the skin parti-coloured pink (King Edward coloration), the flesh white, and the eyes shallow or slightly protruding.

Ulster Prince [1] produces a tuber of a saleable size more rapidly than almost any other variety. The number of eyes is fewer than in other earlies. Blind tubers may occur as a result of scab or skin spot, hence care in the selection of seed tubers is essential. The haulm is of medium height, bushy, and with numerous large white flowers. Cover is slow in developing, but tuber formation is rapid and six or seven tubers are produced per plant. The variety matures at the same time as Arran Pilot. The tubers are large and tender skinned; cracking and second growth are not infrequent. The tubers are kidney-shaped, the skin white and thin, the flesh white, and the eyes shallow.

Craig's Alliance [1] bulks very early and occasionally produces tubers of saleable size more rapidly than Ulster Prince. The haulm is of medium height, moderately strong and bushy with white,

[1] Immune from wart disease.

fairly large flowers. When lifted green, yields are high and comparable with Arran Pilot. There are indications that the variety may be more conveniently classed as an early second early. At full maturity, Craig's Alliance has yielded very heavy crops of well-shaped oval tubers with little or no second growth or cracking.

In the group of varieties which mature fairly early but whose rate of bulking precludes their use as first early varieties, the following have given good results in second early trials :—

Craig's Royal[1] matures during August with a haulm of medium height, strong upright habit, and few red-purple white-tipped flowers. Cropping capacity is better than that of Dunbar Rover and comparable to that of Arran Banner when lifted as a second early. Losses of seed due to soft rots may occur, hence the variety requires careful handling. The tubers are thick kidney in shape, with parti-coloured skin (King Edward coloration). The flesh is cream-coloured and the eyes are shallow. It should be noted that the development of colour is variable and may be entirely absent.

Ulster Ensign[1] matures rather earlier than Craig's Royal, and may best be classed as a late first early. Haulm type is fairly constant, medium in height, with dark-green glossy leaves and white flowers. Cropping capacity, though good, is not so high as that of Craig's Royal. Losses due to dry rot may occur, and care is necessary in handling the seed. In the absence of preventive spraying severe losses may arise from blight. The tubers are of an attractive kidney shape, the skin fine and parti-coloured (King Edward coloration) ; the flesh is white and the eyes shallow. Development of colour is better and more consistent than in the case of Craig's Royal.

Maincrops.—The leading maincrops at the time of writing were Majestic and King Edward VII, and these are described in detail.

Majestic.[1]—Tuber : kidney (pear-shaped to long oval) ; skin white ; eyes shallow ; flesh white ; sprouts faint pink ; second growth takes the form of cracking.

Foliage : haulm of medium height, spreading ; less rigid than that of British Queen. Leaf and leaflets flat, open and smooth, ashy green ; stalks of young leaves with a pink tinge, the colour extending into the midribs ; terminal leaflets oval ; secondary leaflets fairly numerous, small.

Flower : creamy white, profuse, sometimes with a purplish

[1] Immune from wart disease.

tinge on the back of the petals; anthers orange; flower stalk long, slightly bronzed; buds dark with green tips.

This variety is immune from wart disease but is susceptible to blackleg, leaf roll and the three common viruses; its tubers are susceptible to blight. It is an early maincrop and is notable because of its heavy cropping capacity. On good land the tubers may be large and coarse; the texture is generally waxy. The seed is unsatisfactory when cut.

King Edward VII.—Tuber: kidney (oval to pear-shaped); skin white, more or less splashed with pink; characteristically smooth on surface; eyes shallow; flesh white; sprouts pink.

Foliage: haulm erect, tall, branching, tops crowded; stems with a pink tinge; leaves medium green and glossy; leaflets with waved margins, the younger leaflets on top being very small, narrow, numerous, and twisted forward, the last pair fitting round the terminal; secondaries fairly numerous and small.

Flower: red-purple, but seldom formed; buds pink; sepals fairly long; flower stalks short.

The variety is an early maincrop. It is not immune from wart disease and is susceptible to blackleg, leaf roll, and virus Y; it is virtually immune from viruses A and X, and mosaic diseases are very uncommon; all the plants carry another virus (para crinkle) which is unimportant. Bolters and wildings are common. Because of its good eating quality and its suitability for the chip trade it is in great demand in many markets and commands a higher price than most other sorts. It does not do well on light dry land—indeed it requires good land and the drills should not be too wide; it does not respond as well as some sorts to extra heavy manuring.

Red King is a self-coloured variant of King Edward.

Kerr's Pink [1].—Tuber: round, pink, dented at heel; eyes usually medium but sometimes deep; flesh white; sprouts pink.

Foliage: haulm tall and branching; very vigorous; stem strong, tinged pink.

Flower white and freely formed.

Kerr's Pink is immune from wart disease and virtually immune from virus A. Susceptible to virus Y, but does not suffer severely. Susceptible to blackleg and leaf roll. Tubers susceptible to blight. A heavy cropper of excellent cooking quality and popular in Scottish markets. It keeps exceptionally well, but is rather prone to second growth.

[1] Immune from wart disease.

Redskin [1] offers an alternative to Kerr's Pink where self-coloured potatoes are preferred by consumers. It is both earlier and of better shape.

Dr McIntosh [1] is a variety distinctly earlier than Majestic. The haulm is low, compact, and with numerous white flowers. Under average conditions, cover is barely adequate and slow in becoming established. The variety reacts unfavourably to dry conditions. Cropping capacity appears to be somewhat less than that of Majestic, but the tubers are not so prone to cracking or coarseness. The tubers are kidney-shaped and uniform in size, the skin and flesh are white, and the eyes shallow. Cooking quality is good, particularly in regard to colour.

Conference [1] is of similar maturity to Dr McIntosh. The haulm is of medium height and bushy, with numerous white flowers. Cropping capacity is good. The tubers are long oval, the skin white, the flesh cream, and the eyes shallow. Cooking quality is very good both as regards colour and texture, which is slightly more floury than that of King Edward grown under similar conditions.

Arran Peak [1] matures rather later than Majestic. The haulm is strong growing, of medium height, with numerous white flowers. The cover is good. Cropping capacity is good but rather lower than Majestic, though under conditions where Majestic is subject to cracking, Arran Peak often produces heavier yields of saleable tubers. The tubers are thick oval and very even in shape, the skin and flesh white, and the eyes shallow. The skin is thicker than Majestic and the tubers usually travel well. Cracking or second growth is not common. In recent seasons considerable trouble has been experienced with blackening of the flesh due to causes not yet ascertained. Cooking quality is generally less good than with Majestic.

Ulster Supreme [1] matures about the same time as Arran Peak and rather later than Majestic. The haulm is strong growing, of medium height and upright habit, with occasional light-blue white-tipped flowers. The cover is good and the rate of establishment satisfactory. Cropping capacity is, if anything, rather higher than Majestic on most soils. The tubers are oval in shape, tending to flatness; the skin and flesh are white and the eyes shallow. Cooking quality is moderate to good.

Stormont Dawn [1] matures a little later than Arran Peak and

[1] Immune from wart disease.

distinctly later than Majestic. The haulm is medium to tall, strong growing and upright in habit, with white flowers. Cropping capacity is high and yields may be higher than Majestic. The tubers are thick kidney in shape, the skin and flesh white, and the eyes shallow. The skin is rather thicker than Majestic. The tubers travel well. Tuber disease is often obscured by the roughness of the skin. Cooking quality varies with the character of the soil rather more than it does in other varieties.

Selection of "Seed."—As mentioned above, the older sorts of potatoes may wear out and have to be replaced by new and more vigorous varieties, but it is also found that in many localities the yield of a given variety falls off when the farmer propagates the crop for a number of years from his home-grown seed. If, however, he buys in seed of the same variety from a suitable district his yield can be maintained, or considerably improved. As a rule the best seed for a typical lowland potato farm is obtained from a northern and high-lying district. Some of the largest potato growers in the south obtain all the seed they require from Scotland or Ireland each year, while in other districts it is profitable to buy in fresh seed every second year. In Lincolnshire it is a common practice to plant Scotch seed in the upland areas and to use the produce for planting in the fens.

The following table shows the average difference in the yields of twelve varieties grown at the Midland Agricultural College in a trial from Scotch, once-grown and twice-grown seed, the latter not having been isolated from virus-infected crops:—

	Ware	Seed	Small	Total
	Tons	Tons	Tons	Tons
Scotch seed . .	10·05	1·97	0·57	12·59
Once-grown seed .	6·25	1·16	0·51	7·92
Twice-grown seed .	3·45	1·32	0·53	5·30

The main reason why Scotch seed produces such remarkable results is that in cool, upland, and northern districts the climate is not nearly so favourable for the leaf-sucking insects that spread virus diseases from affected to unaffected plants, so that the seed, if suitable precautions are taken in its production, may be relied upon as being relatively healthy. Northern Ireland, parts of the north of England, and parts of Wales are other sources of healthy

stocks. The insect chiefly responsible for the spread of virus infection is the Peach-Potato aphid, *Mysus persicae*.

In the case of early varieties many English growers use "once-grown" seed for the bulk of their planting, since this produces an earlier crop than Scotch seed.

In northern and elevated districts, where there are few disease-spreading insects, it is possible to maintain the vigour of a potato stock by "roguing" out any plants which show signs of virus disease (see p. 344). But where stocks are badly affected it is generally more profitable to purchase a small amount of really first-class stock seed and to propagate it at least a quarter of a mile away from other varieties—say in the middle of a turnip field—so that it will not readily be contaminated. The tubers should be set close together in narrow drills so that a large number of small potatoes may be obtained as seed for the selling crop in the following year.

On all farms where there is a sale for seed potatoes the crops should be rogued during the growing period so that the produce may be certified with regard to purity and health. Early harvesting is desirable, since this prevents late infections from reaching the tubers. Burning off the tops with sulphuric acid or other chemical has the same effect. Special machines for haulm destruction are available.

Government Agricultural Departments have schemes for the official inspection of potato crops during the growing season and the issuing of appropriate seed certificates. The standards that have been adopted in the various parts of the British Isles are *approximately* the same. The Scottish standards and designations are as follows:—

	Varieties Immune from Wart Disease	Varieties not Immune from Wart Disease
Designation . .	S.S.[1] (Scot.[2])	S.S. (Scot.) N.I.
Standard . .	99·95 per cent. pure and true to type and not more than 0·25 per cent. of virus diseases and wildings, including not more than four plants per acre leaf roll, severe mosaic and wildings, and from which all bolters have been removed.	

[1] Stock seed.

[2] The source of the seed is indicated in the brackets: (Scot.) = Scotland; (E.) = England; (W.) = Wales; (Nor. Ir.) = Northern Ireland; (Eire) = Eire.

	Varieties Immune from Wart Disease	Varieties not Immune from Wart Disease
Designation . .	A (Scot.)	A (Scot.) N.I.
Standard . .	Purity of not less than 99·5 per cent., not more than 1 per cent. virus diseases and wildings, of which not more than 0·5 per cent. may be leaf roll, severe mosaic and wildings.	
Designation . .	H (Scot.)	H (Scot.) N.I.
Standard . .	Purity of not less than 99·5 per cent. and not more than 3 per cent. of leaf roll, severe mosaic and wildings.	

" Uncertified " seed potatoes may also be sold, but there are special designations within the group, *viz.* :—

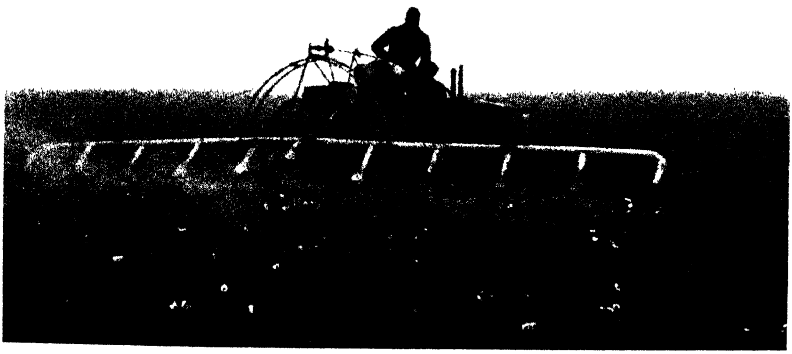
Uncertified (English once-grown) and Uncertified (Welsh once-grown) refer to material from crops that have not themselves been certified but have been produced directly from Certified (S.S., A, or H) seed.

Uncertified (English) and Uncertified (Scotch), etc., include any other potatoes sold for seed. Uncertified stocks must, however, be 97 per cent. true to name.

All potato seed must be the size specified at the time. This is ordinarily such as will pass through a 2¼- or 2-in. mesh and pass over a 1¼-in.

The southern grower who intends to sell his crop entirely as ware may expect quite satisfactory results from seed that has an " H " certificate, and indeed it may be uneconomic to pay the higher price that Scottish stock seed commands. Even where " H " seed is derived from a crop showing the maximum permissable infection (3 per cent.), it is very unlikely that the proportion of infected tubers will be greater than three times this amount —say 9 per cent. Where the infected plants are below 10 per cent. there is no appreciable reduction in yield, a finding that may be explained by the fact that two healthy plants, growing on either side of a diseased one, benefit by the absence of competition. Where, however, the stock in question is intended to provide seed again for a second season, the reduction in yield from the " once grown " seed may be serious. It follows that a higher grade than " H " should be purchased if the intention is to plant the produce again.

Planting Potatoes



Dry Spraying Potatoes

PLATE XXVIII

PITTING POTATOES

SORTING AND BAGGING POTATOES

The size of the seed is a matter of considerable importance, not only with regard to economy in planting but also with a view to the size and number of the tubers that develop in the crop. Before potatoes are marketed it is customary to sort the crop into three grades—namely, ware, which is sold for culinary purposes; seed, which is reserved for planting; and "chats," which are usually fed, along with damaged tubers, to stock. The ware is removed from the rest by passing the tubers over a $1\frac{5}{8}$-, $1\frac{3}{4}$-, $1\frac{7}{8}$-, 2-, or $2\frac{1}{4}$-in. riddle,[1] and another riddle of about $1\frac{1}{4}$-in. mesh is used to remove the chats from the seed. It is obvious that the larger the mesh of the first riddle the greater will be the proportion of seed-sized tubers and the smaller the amount of ware. The shape of the variety must obviously be taken into account; kidney varieties of a given weight will pass through a sieve that would hold back round tubers of the same volume. Farmers who have no market for seed should select a seed riddle having a small mesh, so that they may secure a large part of their crop in the form of a marketable grade. Growers who can obtain a better price for seed than for ware naturally endeavour to sell as much of their crop as possible for seed purposes, and they use a first riddle with as large a mesh as the buyers will tolerate. On the other hand, those who purchase the seed can make a given tonnage plant a much larger area when the tubers are small, and they therefore endeavour to obtain seed that has passed through a riddle with a relatively small mesh. In practice the size of the dressing riddle is therefore determined by the relationship between supply and demand, or by regulations based upon these factors. In some rare cases a new and valuable variety can be sold for seed purposes "as grown." The weight required to plant an acre will obviously depend upon the average size of the sets and their spacing. The latter may range from about 22 by 10 in. to 30 by 18 in. For example, with 2-oz. sets planted in 27-in. drills at intervals of 15 in., the requirement would be about 17 cwt. per acre. Experiments have shown that, assuming Scotch seed to cost in England twice the price obtained for the produce, the most economical size of set is one weighing about 2 oz., *i.e.* about the size of an average hen's egg.

[1] The Potato Marketing Board has power to prescribe the minimum size of mesh over which ware potatoes must pass. The power is used to reduce the quantity of potatoes coming on the market in years when the supply is likely to prove excessive.

What effect has the size of the set on the number of tubers produced by the plant ? Large sets tend to produce several stems and a large number of tubers which, under ordinary conditions of spacing, cannot grow to any great size owing to the competition of neighbouring plants. This is, of course, an advantage if the object is to produce a crop with the maximum possible proportion of seed-size tubers. On the other hand, when small or cut sets are planted, a limited number of stems are produced and the young tubers tend to be few in number but large in size, thus yielding a crop in which ware-sized potatoes predominate. Actually the heaviest yields of ware are usually secured by planting sets that run about seven to the pound. There are large potato-growing districts in Lancashire where there is no great sale for small potatoes but a good demand for ware to supply the industrial population, and to meet this demand the growers sprout full-sized potatoes, cut them to one or two eyes for planting, and in this way obtain the sort of crop that is required.

With regard to the yield per acre, large potatoes on the whole produce a heavier crop than small : this is due to the extra food-content of the large sets enabling the plants to attain a better development. But with very large sets the cost of the extra weight of seed required for planting may not be met by the improvement in yield. Where seed is scarce or of high value, chats or even $\frac{1}{4}$ oz. tips cut from food potatoes may be used for planting. It is generally believed that the ultimate result of growing potatoes year after year from the smallest tubers will be the degeneration of the stock and a decline in yield ; but where the small size of the tubers is not due to disease this is not necessarily so. It is characteristic of small tubers that their sprouts grow slowly. Hence relatively large sets are used for first early varieties.

Examination of experimental results over some twenty years has led to the following conclusions :—

1. Increase in seed-rate results in increased yields. The increase is substantial up to a rate of 15 to 20 cwt. per acre, and falls off gradually until, at rates of 40 cwt. and over, the increase in yield only just equals the increase in seed weight.

2. It appears to make little difference whether the seed-rate is increased by closer planting or by the use of larger sets—*i.e.* the optimum weight of seed is almost the same for large and small sets. Hence there is substantial loss of yield if small sets (chats) are planted at normal intervals.

3. The data are insufficient to show any clear differences as between one locality and another.

4. The most profitable seed-rate will depend on the relationship between the cost per ton of the seed and the price per ton obtained from the crop. In general the most profitable seed-rate, with Scotch or Northern Irish seed, will thus be lower than that with material grown on the farm or in the area where it is to be planted. At the prices prevailing at the time of writing the most profitable rate for Certified " A " seed was 15 to 17 cwt. per acre, whereas with the farmer's own once-grown seed it would be at least 20 cwt.

It is found that when potatoes are cut they can be immediately planted with safety, whereas if the cut sets are exposed for even a short time to drying conditions, organisms are liable to infect the tissues and cause the sets to rot; but if the newly cut surfaces are allowed to heal in a fairly warm and not too dry atmosphere, the risk of decay is greatly reduced. Some varieties that are soft-fleshed—*e.g.* Majestic and Arran Pilot—have to be cut and stored with particular care if rotting is to be avoided. Cut potatoes, if they are to be stored for a considerable time, should be spread out in a thin layer, because if they are bagged or piled up they are apt to heat, and heated seed, either cut or uncut, will produce an inferior yield.

Boxing Potatoes.—For a long time it has been common custom among gardeners to sprout or " chit " their seed potatoes in trays before planting for the early market. Within the last three or four decades, however, the practice has extended to field-grown potatoes, not only in the case of early varieties—although for these it is indispensable—but also for maincrops.

The advantages of sprouting potato seed are numerous, but probably the most important is the increase in yield obtained from sprouted over unsprouted sets, where variety, manuring, time of planting, etc., are the same. This increased yield may be as much as 2 tons per acre and is usually very considerable; it is doubtless brought about in part by the longer period of growth, as sprouted plants are through the ground from a fortnight to three weeks before the others; but it is probably also connected with the fact that the whole energy of the set is preserved when it is boxed, whereas if pitted it may waste a good deal of its substance in producing a long, weak shoot which breaks off in the subsequent handling. Sprouting also allows the crop to be planted late in a bad year and lifted early in a late district, and the earlier ripening

reduces the season when there is most risk of blight. The practice has, on the whole, a beneficial effect on eating quality, as it reduces the chances of the crop being lifted while the tubers are immature.

Carefully boxed potatoes keep better than sets that are allowed to remain in the clamp until setting time; the skins of the former become tough and rubbery, especially if they are exposed to a preliminary greening, and they suffer little from shrinkage. Another advantage of boxing is that the seed can be gone over and any tubers that fail to produce buds, or show signs of disease, can be removed; also the colour of the sprouts may indicate the presence of rogues and these can be separated.

Sprouting is carried out by placing the seed in shallow boxes or trays. The best results are got when this is done immediately after lifting, but it is worth doing even as late as a month or two before planting. Different sizes of boxes are used, the larger being less costly per ton of seed but rather more difficult to handle at planting time; the small sizes have cross-spars and can be conveniently carried by a single worker. When the boxes have been filled they must be stored in a suitable building where they will receive plenty of light and ventilation, and where there is no risk of the temperature falling below freezing-point. In Lincolnshire many growers have erected large glass-houses, provided with simple heating apparatus for use in the coldest weather, in which they sprout the whole of their seed. The houses are sometimes used in summer for other crops, generally tomatoes. It is inadvisable to keep the buildings at a high temperature; but during periods of severe cold and threatened frost the heat should be turned on to avoid any risk of the potatoes being damaged. Potatoes freeze if maintained for a short time at a temperature below 27·1° F. and are then useless for seed; but seed that is only "chilled" sometimes gives poor results. The optimum temperature range, to avoid both chilling and sprouting, is 36° to 40° F. Rapid sprouting occurs at temperatures above 44° F. The boxes are stacked in tiers so as to economize space, but they must be rearranged from time to time so that all the sets are exposed to light. When potatoes are sprouted in the dark the shoots are long, thin, and weak, and when handling takes place before planting, the stems tend to be broken off, thus diminishing the food reserves of the tuber and causing a considerable loss of time before new shoots develop. Nevertheless sets that have long shoots do well if they are carefully handled. There is a wrong belief that long

sprouts should be broken off; it has been demonstrated that this leads to a diminution of the crop. The most desirable sprouts, which develop when the tubers are exposed to plenty of light, are short—not exceeding 2 in.—strong, and well greened; they are not easily broken and develop rapidly when the sets are planted.

Recent research in Holland has shown that potatoes may be successfully "chitted" in insulated buildings—*e.g.* converted barns—with the aid of artificial fluorescent lighting; but special ventilating equipment is required to keep the temperature within the limits mentioned above.

When circumstances permit, beneficial results are got by exposing seed to direct sunlight before it is boxed. The small grower would do well to raise a portion of his tubers before they are quite mature, green them to harden them off, and box them for the next year's setting.

CULTIVATION OF POTATOES

Soil and Climate.—The most suitable soil for potatoes is a light deep loam or alluvium, but the crop does well on black-top or peaty land. The potato is one of the few farm plants that tolerate a rather highly acid condition of the soil, but the yield suffers where there is an extreme deficiency of calcium. Except in cases where very acid moorland or bog is being reclaimed, liming shortly before planting should be avoided, since the yield is reduced rather than increased and there is risk of inducing common scab (see p. 340). When grown on peaty land potatoes can produce a heavy yield; but the quality is somewhat poor, and on the English market they command a price below the average. The finest quality is obtained from the loams of the Old Red Sandstone formation, which produce potatoes that do not darken after boiling but remain pure white. Potatoes do badly on heavy soils and under wet conditions, and farms situated on such land seldom produce the crop at a profit. It is, however, true that the crop has recently spread on to soils that formerly were considered too heavy; particularly in the drier areas of East Anglia. The development is largely due to the possibilities, opened up by the heavy crawler tractor, of deep ploughing in early autumn and thorough cultivation in the spring. The main remaining difficulty is lifting, and it is necessary to select varieties that mature soon

after the cereal harvest when the land in most years is still dry. Naturally there is a risk that, in wet autumns, lifting may be difficult or even impossible.

As potatoes are cultivated on a field and garden scale from the dry east coast to the heavy-rainfall districts of Ireland, it may be concluded that they thrive under our whole range of climatic conditions; but in very wet seasons the liability to blight is much accentuated, and there is great difficulty in securing the crop from the water-sodden soil. Warm, light-land districts bordering on the sea-coasts are ideal for the production of early varieties, because the sets can be planted as early as February without fear of destruction of the young plants by late frosts. The best potato soil is one that admits of liberal manuring; it does not require to be naturally rich. Many areas devoted to the cultivation of early potatoes have a northern or western exposure, while land lying to the south or east in the same districts is unsuitable. This is because late frosts are inevitable, but where the plants are gradually thawed, as when exposed to the north, they are not injured. On the other hand, where rapid thaw is produced by direct insolation, the leaves are stricken to the ground. Frost does not necessarily kill the plants, but in having to replace the lost foliage the potatoes receive a serious setback.

The most favourable seasons are those of moderate rainfall: in rainy seasons the temperature is too low for optimum growth and, as mentioned above, the incidence of blight tends to be high; in dry summers the yield is often limited by the water supply. The best eating quality is generally obtained when the last phase of the growing season is fairly dry, as it is then that the tubers are formed with the lowest moisture-content. On the other hand, any premature check in the deposition of starch in the tissues—as when the foliage is destroyed by frost or blight—results in a watery potato of poor eating quality. Second growth, which is most common when rain comes after a dry summer, seriously reduces the quality of the crop. It takes various forms such as unsightly cracking in Majestic, prolongation of the tuber and "glassy end" in Golden Wonder, knobbiness in British Queen, and the formation of runners and secondary tubers in Kerr's Pink.

Place in Rotation.—Potatoes are usually taken between two straw crops so that the rotation receives a maximum of benefit from the cleaning of the land. On some of the best potato soils, potatoes have been cultivated year after year without failure,

but in many cases this practice has resulted in the infestation of the soil with potato-root eelworm, a very serious pest. The early sorts may be followed by a quick-growing catch crop of mustard, rape, white turnips, ryegrass, or by winter crops such as broccoli or cabbage. Potatoes do exceptionally well after old grass and, if the land has been rendered very rich through a long period of grazing with heavily fed stock, are a safer crop than oats or wheat. The decaying sod provides the humus that is so necessary for high yields, and on a system of farming where the dung supply is somewhat short, it is always advisable to grow a portion of the potato crop in this place in the rotation. Before deciding to plant potatoes after old turf it is desirable to have an estimate of the wireworm population. With a very heavy infestation potatoes should be avoided. With moderate populations, at least in the southern part of the country, second earlies may escape with little damage, the point being that wireworms tend to descend into the deeper zones of the soil in periods of drought and heat. In some places potatoes are grown after peas or vetches or after red clover, the aftermath being preferably ploughed in as green manure.

Preparation and Planting.—As the potato crop usually receives a dressing of dung, the management of the cultivations will depend very largely on the time of the year when the manure is applied. It is usually most economical of labour to apply the dung during the winter, when other work is not pressing, and plough it in as soon as possible. When this has been done and the ploughing completed, the land, as early in spring as it becomes workable, is worked into a deep, loose (but not necessarily fine) tilth. This may be obtained by reploughing with a digger plough and a subsequent harrowing; or by cultivating and harrowing. Repeated crossing of the land with cultivators and harrows should be avoided, especially if the subsoil be still wet, as this leads to undesirable treading and consolidation. If, therefore, it is clear that a good deal of tillage will be necessary it is usually better to replough. The land is then drawn into ridges for planting by means of a double mould-board plough or a special machine that is capable of forming two or three ridges at a time, though an ordinary plough can also be used. When the dung is applied in spring it is spread between the ridges, and the potato "seed" is placed directly on the manure. This method of application gives very good results, as the manure decomposes immediately

round the plant roots ; but the carting and spreading are slow and laborious at a time of the year when much other work has to be performed. In the dry areas of eastern England it is important to conserve moisture. Ploughing should therefore be done in autumn, and spring tillage should be reduced to a minimum.

When the crop is taken after a tough old lea the preparation is frequently much more difficult, as the sods take a long time to decompose and tend to work to the surface during the cultivating and ridging operations. Under such circumstances the disc harrow is a valuable implement. In deep soils this difficulty can be more completely overcome by double ploughing. For this purpose two ploughs are required : the first skims off the whole of the sod and turns it into the bottom of the furrow : the second plough, following in the same furrow, cuts about 6 in. deeper and throws its furrow-slice on top of the turf. Many soils are too shallow to allow of such deep cultivation, but can be worked according to the same principle, though on a smaller scale, by fitting each plough with an efficient skim coulter to bury the turf.

The time of planting depends upon the district and the variety that is being grown, the risk of early planting being in proportion to the liability of the district to late frosts. At the one extreme, in small frost-free pockets on the Cornish coast, earlies may be planted about Christmas. February or early March is usual in the general run of coastal areas where first earlies are grown. Early April is the time for setting maincrops—the earlier the better—so long as the land is in fit condition. In the average season every week's delay after 10th April results in a loss of about half a ton in the yield. Moreover, the response to dung and fertilizers (especially potash) is much reduced by late planting. This is illustrated by a five-year series of experiments at Rothamsted which gave the following average yields (tons per acre) :—

	Planted 14th April	Planted 30th May
No manure	7·1	6·0
Farmyard manure only	11·2	8·5
Potash only	10·1	7·0
Farmyard manure and potash	12·8	8·4

It is a matter of prime importance that the land should be sufficiently dry and in good working order at planting time, as a crop set in cold wet soil seldom develops satisfactorily.

The distance between the potato drills should be varied according to local circumstances and the requirements of the crop. When potatoes are grown for the early market, and their growing period is too short to allow them to benefit by abundant space, it is usual to have the drills comparatively close together (about 22 in.) and to set the tubers about 1 ft. apart. For exceptionally early marketing even closer intervals should be adopted. Maincrop potatoes, however, because of their long growing period, require more room to develop, and it is usual to place them in 26- or 28-in. drills and to set them at intervals of 15 to 20 in. Nevertheless, where the land is very rich and the potatoes tend to attain an excessive size, or where it is desired to obtain a large proportion of seed, the tubers may be set at lesser intervals. A large drill width facilitates cleaning, and 28 or even 30 in. may be desirable if the land contains much twitch. In this case, however, a variety with a large spreading top should be selected, otherwise the weed-smothering effect of the crop is largely lost.

The table below sets out the weight of seed required in relation to the size of the sets and the spacing. The average size of sets from a given set of riddles will, however, vary slightly as between round- and kidney-shaped varieties.

Seed Requirements per Acre

Width of Drill	Distance between Tubers	Plants per Acre	Tuber Size and Hundredweight Seed per Acre			
			2½ to 3½ oz. 2¼ by 1¼ in.	2 to 3 oz.	2 oz. 2 by 1¼ in.	0·6 oz. Chats
In.	In.		Cwt.	Cwt.	Cwt.	Cwt.
27	12	19,360	35	29	22	6½
27	14	16,594	30	25	18½	5½
27	16	14,520	26	22	16	4¾
27	18	12,907	23	19	14½	4¼
28	12	18,669	33	28	21	6¼
28	14	16,002	29	24	18	5¼
28	16	14,001	25	21	15½	4½
28	18	12,446	22	18½	14	4

The depth of the drills is varied according to whether the land is dunged on the flat or in the drill, more depth being required in the latter case. It is advisable that early planted crops, and indeed all crops in districts that are liable to late frosts, should be deeply

set so that the sprouts may receive adequate protection during the early stages of growth; they can be brought nearer the surface by harrowing down the ridges when the danger of frost is past.

Many crops are still set by hand, but there are now satisfactory potato-planting machines which, if considerable areas are grown, soon repay their cost in economy of labour. Machines have the further advantage, in the drier parts of the country, that their use conserves soil moisture by reason of the speed at which the operation is carried out. While most of the mechanical planters do good work with ordinary seed they are unsuitable for planting sprouted potatoes, as they break off the majority of the shoots. It is possible, indeed, to obtain a planter that can take both sprouted and cut seed, but extra hands are required to sit on the implement and drop the sets, one at a time, into the planting apparatus: they are nevertheless more speedy and economical than planting by hand. These machines can, of course, be set to drop the tubers at any desired intervals.

In planting by hand, or by a machine that does not cover the sets, the ridges have to be split back. This is normally done by tractor, with front-mounted ridging bodies, the tractor wheels following in the furrows. With trailed equipment special precautions are necessary to avoid running over the sets. If a horse-drawn ridging plough is used, the near-side horse should be trained to walk on top of the ridge. It is important, with mechanical planting, that a two-row planter should be used in conjunction with two-row cultivators, and a three-row planter with a three-row cultivator.

Manuring.—The basis of potato manuring should be a dressing of good farmyard manure, and the only occasions when this may be neglected are when the crop is taken after a rich old pasture, where seaweed is available, where green manuring has been carried out, or on certain peculiarly rich soils such as the black fen. The amount of dung applied varies from 12 to 20 tons per acre; but if the land is rich the smaller quantity should be used, as 20 tons would then tend to produce rank and luxuriant foliage without increasing the yield. Best results are usually got by applying a limited amount of dung supplemented by artificials. No plant is more dependent on potash supply than the potato. Some soils contain all the potash the crop requires, but on others the nutrient is deficient and a liberal dressing should be given As in many other plants, severe potash deficiency produces easily

recognizable symptoms in potatoes. The condition is called "leaf scorch" and consists in the premature browning of the leaves. Sulphate of potash was long preferred to other forms and was thought to give better cooking quality than the muriate; but the difference is small, and the yield response to the muriate is equally good. Large amounts of chlorides, as contained in kainit and "potash salts," may have deleterious effects. Hence, if the only available form is kainit or other low-grade salt, it should be applied very early so that it may be well washed by the winter rains. Potatoes practically always respond to sulphate of ammonia, the form of nitrogen that is usually employed. Where phosphoric acid is required—there are soils that are sufficiently well supplied—superphosphate is quite the best fertilizer.

For soils that are neither exceptional in their deficiencies nor abnormally rich in particular nutrients, a suitable mixture for second early and maincrop potatoes consists of 2 parts of sulphate of ammonia, 3 to 4 parts superphosphate, and 1 to 2 parts sulphate or muriate of potash. A mixture of $2 : 3\frac{1}{2} : 1\frac{1}{2}$ contains about 6 per cent. nitrogen, 8 per cent. phosphoric acid, and 10 per cent. potash. The smaller proportion of phosphates should be applied on land where phosphates are used liberally for the other crops in the rotation and where there is therefore a fair reserve in the soil, while the larger proportion should be employed where the soil has received little of these fertilizers for a number of years. Excess of phosphate causes the plants to die down early and so shortens the growing season. With regard to potash, the smaller proportion may be sufficient on soil that has plenty of body and on land that has been generously dunged. The larger proportion will be needed on lighter soils or where little farm manure has been applied, or where crops of sugar-beet or potatoes (which remove large quantities of potash from the farm) are frequently grown.

The following quantities of the mixture are likely to yield a profitable return when used in conjunction with moderate dressings of dung. On poor potato land that does not normally yield more than 6 to 7 tons of potatoes per acre, apply 6 cwt. per acre. On land that may yield 8 to 10 tons, apply 8 to 10 cwt. per acre. On good land that can yield 11 to 13 tons, apply about 12 cwt. per acre. Where no farm manure has been employed the standard dressings may be increased by about 50 per cent., but not more than 10 to 12 cwt. of highly soluble fertilizer should be applied per acre without some regard to its placement, for a greater amount

in contact with the sets may interfere with the normal development of the roots. However, where measures are taken to prevent contact damage, over 20 cwt. per acre has been used successfully in this country and up to 25 cwt. in America. Naturally the optimum dressing will vary, apart from soil conditions, with the relation between the price levels of fertilizers and potatoes (see Part IV, Chapter III). In all these examples it is of course possible to use equivalent quantities of concentrated fertilizer.

With hand-planting correct fertilizer placement is highly important. The fertilizer should be broadcast over the ridges, because 10 cwt. so applied produces as great a response as 13 cwt. applied before ridging. When using a planting machine that works from the flat, the fertilizer should be thoroughly worked into the top 3 or 4 in. of soil. Where the planter has a fertilizer attachment the maximum amount of ordinary compound that can be applied with safety is about 12 cwt. per acre, even if the soil is at optimum moisture-content; if more fertilizer is to be applied it should be worked into the top soil in advance of planting. Machines which place the fertilizer in bands permit the use of quantities of the order of 18 cwt. per acre. See further under Fertilizer Placement (p. 111) and Potato Planters (p. 225).

With optimum placement the response to a given dressing may be half as high again as that obtained by the least efficient method—*i.e.* broadcasting before ridging.

Early potatoes are manured very liberally in order to force them to bulk and mature early. In the early district of Ayrshire it is common to apply, in addition to as much organic manure as is available, mixed artificials at the rate of 13 to 15 cwt. per acre. The general belief is that the mixture should be rich in nitrogen and phosphates but relatively poor in potash, and 15 cwt. of a common early potato compound would represent nitrogen equivalent to over 6 cwt. of sulphate of ammonia, about 1 cwt. of muriate of potash, and the remainder phosphates of different grades.

In many coastal districts seaweed is used for potatoes and produces very good results. Ton for ton it is slightly better than dung, its superiority being due to its higher potash-content.

After-cultivation.—Probably no crop receives more cultivation than the potato, because from the covering of the sets until the plants meet across the drills there is an opportunity to improve the tilth and systematically to destroy weeds. The sequence of operations depends on local custom and the available imple-

ments ; it should also be determined by the time of planting, the rate of growth, and the importance of weed destruction. A common method of working potatoes in the north is, after planting, to leave the drills for two or three weeks until the weeds begin to appear, then to harrow them down with saddle-back or chain harrows and, almost at once, to run them up again with a ridging plough. This moves the soil without actually exposing the tubers, thereby killing the weeds and encouraging more to grow, yet it does not leave the sprouting sets for long near the surface and incompletely protected against frost. The next operation, performed maybe a fortnight later, when the risk of frost is reduced but before the sprouts are too long, is to harrow the drills down again. This harrowing should be timed so that it leaves the tops of the shoots just below the surface. The field is then left until all the plants are through the ground and show the rows quite distinctly. At this stage, before the potato roots have spread far enough to suffer damage, a two-horse drill grubber or tractor-mounted cultivator is used to stir the soil deeply. The traditional practice is to give one hand-hoeing and, later on, a further "walk through" to chop out any weeds that later appear or may have been missed. To-day many of the best growers in the drier parts of the country dispense with handwork altogether. Alternate harrowing down and ridging up are continued until some time after the plants have emerged, even up to the point when this results in the breaking off of an occasional sprout. Inter-row cultivations are continued until the tops are widely spread. Earthing up should be done when the soil is rather damp so that it packs properly. Row-crop tractors with drill equipment can be used instead of horse implements. Even after the potatoes have been earthed up, hand pulling of weeds may be continued. If part of the crop is intended for seed, it is necessary to go through the field when the plants are in flower and to remove all "rogues," so that the purity of the variety can be guaranteed. Bolters, wildings, and plants affected with virus diseases should be removed at the same time.

The chemical control of weeds in potato crops is not recommended as a normal practice. It is true that numbers of growers have used MCPA or 2-4D without apparent harm, but critical experiments, so far as they go, suggest that there may be some loss of yield. Only if a crop appears likely to be smothered should resort be had to chemicals.

Spraying.—Perhaps the greatest loss sustained by potato

growers is due to the ravages of blight. It has been found that this pest can be checked to a considerable extent by spraying the crop with a suitable fungicide. Not only do the chemicals stop the growth of the fungus but their application tends to prolong the growing period of the crop, and the longer growing season results in an increased yield. Potatoes grown in the south and west suffer more from the disease than those cultivated in the drier eastern counties, but in a wet season the ravages of blight are very severe and the whole country suffers. There are, of course, districts where blight is so seldom serious that it may not pay to spray every season on the chance of protecting the crop in a " disease year." Most intensive growers, however, find that regular spraying is well worth while.

To prepare Bordeaux mixture for spraying, 4 lb. of copper sulphate should be dissolved in 35 gals. of water in a wooden barrel, and 2 lb. of freshly burned quicklime[1] should be slowly slaked and made up to 5 gals. of "cream." The lime should then be poured slowly through a sieve into the copper solution, which should be kept thoroughly stirred, when a fine flocculent precipitate of copper hydroxide, which is the active ingredient of the fungicide, is produced. It is important that no free copper sulphate be left in solution as it is poisonous and injures the crop. To find out if sufficient lime has been added to cause a complete precipitation, introduce a polished knife blade: it will become coated with a thin film of copper if any of the soluble salt is present. An even more critical test is the addition of a few drops of ammonia which, if free copper sulphate be present, produces a deep blue coloration. Burgundy mixture may also be used. This is prepared by dissolving 4 lb. of copper sulphate in 35 gals. of water, and 5 lb. of washing soda in 5 gals. of water, and mixing the solutions. These mixtures containing 1 per cent. copper sulphate are practically as effective as the 2 per cent. mixtures which are sometimes employed; but in some districts where two or three treatments are given the stronger spray is used for the last dressing. As the mixtures begin to deteriorate in a few hours they should be made up as required and used immediately. Proprietary preparations containing other copper compounds in colloidal or very finely divided condition are sold ready for mixing with water.

[1] In theory 1 part of lime should be sufficient to precipitate 4 parts of copper sulphate, but, allowing for impurities in the lime, it is not uncommon to use the above quantity, or even equal proportions.

Strictly speaking, they are not Bordeaux or Burgundy mixtures and should be called potato fungicides. They are quite effective. Ready-made Bordeaux and Burgundy mixtures are obtainable but are hardly as good as two-solution mixtures prepared on the farm.

With the older standard types of spraying equipment, from 50 gals. (when the plants are smallish) to 100 gals. (when the foliage is full) are required to spray an acre. Recently introduced machines, giving a very much more finely divided spray, give satisfactory results with very considerably smaller quantities. The time of spraying is very important, and as the time varies in different districts it is impossible to lay down any hard-and-fast rule, but on the whole the first spraying should take place in the latter part of June in the south-western counties, in mid-July in the Midlands, and in the last week of July in the northern counties, or it may be given as soon as the first blight is observed in the locality. "Blight weather" cannot be recognized with certainty, since spore production depends upon a combination of temperature and humidity conditions that prevail within the crop. A system of blight warnings, based on accurate determination of these factors, was under trial at the time of writing. It is worth noting that the earliest signs of blight are generally to be seen not in fields of potatoes but in the plants growing on the sites of the previous year's clamps. The best results are got when at least two sprayings are given, the second application being a fortnight to three weeks after the first; but in some of the wetter localities it is profitable to give three or even four dressings, especially when the weather is damp and misty. The spraying nozzles must be kept free from sediment so that the finest possible spray is obtained, and, as far as is practicable, both sides of the leaves should be coated.

Dry spraying or dusting the foliage with a prepared powder containing copper salts is a much less laborious and faster process than wet spraying, and gives fairly satisfactory results. It is a useful alternative on farms where water is difficult to obtain or where very large areas of potatoes are grown. Light dustings of 10 lb. per acre when the foliage is small and 20 lb. per acre when the foliage is full can be applied at almost weekly intervals in a bad season, the best time being early morning or evening when the plants are wet with dew. The copper-lime and other copper dusts are all manufactured products; they should contain the equivalent of not less than 15 per cent. metallic copper, and should be very

fine so as to produce a good "cloud" and give the best possible dispersion.

Lifting Potatoes.—Maincrop potatoes are lifted when the foliage has died off and the growing season has come to an end. At this time, too, the skins of the tubers are thickened by a deposit of corky tissue, and they suffer much less through mechanical injury and keep better than when they are lifted early in the season. The time of lifting varies according to the season and the locality, but most crops are secured between the middle of September and the first week in November. The tubers are brought to the surface by a potato plough, a spinner, or an elevator digger, to be picked up by hand. Mechanical harvesters were still in the experimental stage at the time of writing, but it then appeared likely that success was obtainable at least on relatively light and stone-free soils. The plough is probably less injurious to the crop, but it does not scatter the tubers well, and many are left covered by soil; the old "spinner" type of digger, on the other hand, may slice and bruise a few tubers, but it greatly facilitates gathering—an operation which at best is laborious and expensive. The "elevator" type of digger, which, however, works satisfactorily only on the lighter soils, causes very little damage and leaves the tubers well exposed in a narrow band and even more convenient for gathering. In late districts the crop must, in many years, be lifted long before the haulms would have died down, otherwise frost damage would be very probable. Moreover, haulm destruction may be very important in relation to the prevention of blight infection of the tubers (see p. 343). Again, where the crops are being grown for seed, it is often necessary to bring growth to a stop when the tubers have reached the desirable average size.

On a small scale the tops may be mown with a scythe. The large-scale grower has a choice of several methods. The most effective is to spray with 18 to 20 gals. per acre of undiluted commercial sulphuric acid (B.O.V.) or with about 15 gals. of this to 100 gals. of water. This is normally a task for contractors, since a special type of machine must be used and special precautions observed. Almost as effective is an application of 25 to 30 gals. per acre of a tar-oil fraction which is known commercially as T.O.F. 54. A low-volume sprayer is required. Sodium arsenite and sodium chlorate may be used, with appropriate precautions.

PLATE XXIX

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POTATO BLIGHT ON LEAF AND IN TUBER

BLIGHT ON TUBER

M. Noble

DRY ROT

PLATE XXX

HEALTHY PLANT — POTATO WITH LEAF ROLL

HEALTHY PLANT — POTATO AFFECTED BY MOSAIC

Another possibility is to use a special machine which disintegrates the tops by beating them with steel or rubber flails.

One gatherer will work at about one-twentieth of the rate of a horse-drawn digging machine when lifting an average crop, and twenty gatherers will therefore be necessary to keep pace with a machine digging in both directions; but more workers will be required for a heavy crop. An ordinary light tractor can pull the digger about half as fast again as a team of horses, but with the spinner type of digger rather more damage is done at the higher speed. The cleanest work is done if a one-horse harrow is drawn along each bout after the pickers have gathered all tubers that the digger had exposed. A few minutes are allowed before the digger comes round again.

Except in specially favourable localities—the Cornish and Pembroke coastal areas—lifting of early potatoes commences in June, long before the tubers are hardened or the foliage has ceased to function, and, as mechanical digging is sometimes impracticable, the crop may be raised by hand, using a three or four flat-pronged digging graip or fork. When this is done a gatherer works with each digger, and not only lifts the potatoes but, using two containers, separates them into saleable and undersized tubers. An average daily output is about 2 tons per fork. The potatoes are then packed, preferably into barrels, which are more protective than bags, and sent straight from the field to the market. Owing to the greater cost of hand-lifting and the difficulty in getting the large squads of experienced workers that are required, this method of lifting is practised as a rule only with first and second earlies that command a high price and are too immature for machine digging.

After the preliminary gathering has been completed the field is given a good harrowing to bring to the surface any tubers that have been missed or overlaid by soil; they are then collected and removed in the usual way. The harrowing and gathering may be repeated if it seems that the results will justify the cost. Chain harrows are very good for rolling up the shaws, which can be heaped and burned when sufficiently dry.

Storing Potatoes.—The crop is secured as it is lifted by putting it into a "pit" or "clamp," or by storing it in a shed. The principles of clamping are the same throughout the country, the construction being designed to protect the potatoes from frost and rain and at the same time to allow a certain amount of

ventilation. The clamp, which is made as long as is necessary, and generally from 4 to 6 ft. wide, is commenced by excavating the soil to the depth of a few inches, or simply by levelling the surface of a piece of land that has a good natural drainage and is adjacent to a cart track. It is important to choose a well-drained site since a few days' immersion is enough to kill the tubers. The tubers keep best in narrow pits, but these are more expensive in straw and in labour. The common dimensions take from 10 to 20 cwt. per yard run. The potatoes are tipped on to the pit bottom, dressed up as steeply as possible, and immediately covered with good wheat or rye straw to a depth of nearly a foot. The straw should be kept as straight as possible, so as to shed rain. Soft straw, such as barley, may be used along the ridge. The straw is then covered to within a foot of the top of the clamp with about 2 in. of soil, so that there is ample ventilation to allow the heat, produced by fermentation and respiration, to escape. Some heating due to these causes is quite normal, but in the presence of sufficient moisture and the absence of ventilation the bacteria may become so active that the temperature rushes up, the potatoes are literally cooked, and the clamp collapses. The risk of this is greatly increased if a considerable proportion of the tubers is bruised, cut, frosted, or affected by blight or other fungoid disease. Such samples should be marketed at the earliest possible opportunity. Alternatively they may be dressed before pitting, the unsound material being fed to pigs or cattle. It may also be cooked and ensiled for later use. After a few weeks, however, when the free moisture in the clamp has decreased, and the respiration of the tubers has become less active, the clamp should be earthed up a second time so that there is a covering of about 6 or 8 in. of soil to protect the contents from frost. This earthing up may be done quite soon if the crop has been pitted in dry condition. Where wet pitting has been unavoidable the earthing up should be delayed as long as seems safe so that the excess of moisture may be driven off by the heat of fermentation, but even at this stage bunches of straw should be allowed to protrude at intervals along the apex to allow a certain amount of aeration. If the pit runs east and west extra cover should be given to the north side.

Where the grower has quantities of surplus straw a labour-saving method of storage is to build walls, two bales high and about 6 to 8 ft. apart, packing loose straw between the bales to

make the walls wind proof. The potatoes are placed between the walls and piled up to a ridge in the middle. The top is covered with a layer of loose straw and is finally thatched.

A new method of storing potatoes in this country is to put them in large specially-built sheds, some of which cover an area of 100 by 45 ft. and have doorways which allow the entry of carts or trailers. In these buildings sound mature tubers can be piled to a depth of about 5 ft. and immature soft varieties to 3 ft. Straw is spread over the surface to prevent greening and as a protection from frost. In winter the crop can be dressed by power-driven machines, the workers being protected from inclement weather and provided with artificial light when necessary.

In order that the crop may keep well it is important that the tubers be stored in as dry a state as possible ; moisture encourages bacterial and mould growth which produce rapid deterioration. Harrowings, which consist largely of inferior and damaged potatoes, should be stored separately and used up as early as possible.

An inevitable loss, due to respiration and disease, goes on while potatoes are in store, and the condition of the tubers should be inspected every two or three weeks so that they can be sold and despatched at once if they are found to be deteriorating rapidly.

When potatoes are held over until the spring considerable loss of weight and of food value results from sprouting. Much experimental work was in progress at the time of writing on the value of various chemicals as sprout depressants. Among the most promising were the chlorinated nitrobenzenes and iso-propyl-*n*-phenyl-carbamate. A different approach, also showing promise, was the application of Maleic hydrazide to the foliage a short time before harvest.

Marketing potatoes consists of grading them as outlined in a previous section (see p. 321), picking them over to remove diseased or broken tubers, and either weighing and bagging them or carting them in bulk to wharf or railway wagon. With earlies, however, the soft skins may make it necessary to market the first lots in rigid containers.

When potatoes are ensiled they should first be steamed (boiling adds too much water) until they are soft, then mashed by treading into a small silo or a trench lined with waterproof paper. The mash packs too closely to admit much air, but topping with earth is an additional precaution against wastage.

Yield.—An average crop of potatoes will yield about 8 tons per acre, but 16 tons and over may be got in good districts in favourable seasons. When ordinary riddles are used for dressing, about 7 and 25 per cent. of the crop may be sorted into chats and seed respectively, but the proportions actually vary very greatly.

POTATO DISEASES

The following is a broad grouping of the common potato diseases together with notes according to their importance.

A. Diseases affecting the tuber only, and that superficially :—

(*a*) **Common or Brown Scab** (*Streptomyces scabies*).—The scabbing gives the potatoes a very unsightly appearance, but has little effect on the yield. However, tubers badly affected about the eyes should not be used for seed. The attacks are rarely troublesome where the *p*H of the soil is 5·6 or less ; they are worst on sharp soils and after liming, because these conditions promote a rapid loss of humus and cause the fungus, which can live saprophytically on decaying organic matter, to pursue a parasitic existence. It has been shown on a small scale that the placing of grass cuttings in the drills at planting time will give the fungus material to work on and prevent the developing tubers from being attacked. The disease may be controlled on soils that are free from infection, but otherwise of a type favourable to the fungus, by treating affected seed with a proprietary organo-mercury compound or with a dilute (1 : 1,000) solution of corrosive sublimate. But the fungus is so widely distributed that the treatment is rarely worth applying. Where the suppression of the disease is secured by allowing the soil to remain slightly acid, there may be considerable difficulty in growing successfully such crops as barley, sugar-beet, and red clover. In such a case it is necessary to make a detailed survey of the soil reaction of the individual field and to adjust the application of lime from place to place according to local variations. The aim should be to get the reaction uniform at about *p*H 5·6. The lime should of course be applied as long as possible before potatoes are to be grown. In the United States, varieties showing a high degree of resistance to scab have lately been released in commercial quantities.

(*b*) **Powdery or Corky Scab** (*Spongospora subterranea*).—This form of scab may be indistinguishable from common scab and in its mild form does practically no harm. Where potatoes

are repeatedly grown on the same ground, however, the attack may be so severe as to form a canker not readily distinguishable from wart disease and render the affected tubers useless. To control the disease, plant unaffected seed and do not grow the crop frequently on the same land. Dipping as for common scab is helpful provided the soil is not full of the disease organisms.

B. Diseases which cause the tuber to rot :—

(*a*) **Sprain and Internal Rust Spot.**—These conditions are most prevalent in dry seasons on light soils ; they are not perpetuated through the planting of affected seed but are probably related to soil conditions. Sprain, which is also called spraing, takes the form of concentric rings of dead tissue within the tuber and may show as raised arcs beneath the skin. The other disease takes the form of flecks of dead tissue which are revealed when the tuber is cut ; there are no external symptoms. Both conditions render the affected tubers unfit for the table.

(*b*) **Dry Rot** (*Fusarium caeruleum*).—This fungus does most damage to the seed of early varieties in boxes during the storage period. The affected tubers shrivel and become dry and wood-like ; they should be removed and burned. The trouble is rarely severe in pitted potatoes but may develop a few weeks after the pit has been opened and its contents aerated ; consequently it may break out in consignments of seed that looked quite normal at the time of shipping. Since *Fusarium* is essentially a wound fungus the disease is most likely to spread when the potatoes have been bruised through careless handling. It may be controlled by disinfecting the seed immediately after lifting. Dry powders, such as Fusarex, are most convenient for this purpose.

(*c*) **Gangrene**.—This disease is caused by *Phoma sp*. and, like dry rot, it develops in storage. An affected tuber develops pits or cavities which are lined with mycelium. Control as for dry rot.

(*d*) **Wart Disease** (*Synchytrium endobioticum*).—This disease came into prominence about the beginning of the present century because of the increasing area of the land affected, the loss occasioned by its ravages, and the methods established for its suppression. The fungus produces wart-like excrescences at the eyes of the tubers and on the basal shoots of the plants. The outgrowths are at first white but later become dark brown in colour, and vary from the size of a pea to a warty mass that envelops the whole tuber. The disease is propagated from year to year by spores that are liberated in the soil, and as the organism is capable

of existing in a latent state for many years, it is practically ineradicable.

Fortunately the existence of immune varieties makes the growing of healthy crops on badly infected soil still possible, but if any other kinds are cultivated there is no possibility of starving out the fungus and of getting the land clean. For this reason the Departments of Agriculture have found it necessary to define certain disease areas in which only varieties that have been proved immune may be planted. It is also necessary to prove that the purchased seed is true to type and contains no susceptible rogues ; and growing crops destined for the seed trade must be inspected and passed for purity by the Departments' officials before a certificate is granted entitling their sale in a disease area.

C. Diseases which attack the foliage but not the tubers :—

(*a*) **Stalk Disease** (*Sclerotinia sclerotiorum*) occurs in the west of Ireland, particularly where potatoes are grown repeatedly on the same land.

(*b*) **Botrytis Disease** (*Botrytis cinerea*) rarely does serious damage.

D. Diseases which attack the whole plant and destroy both haulms and tubers :—

(*a*) **Blackleg** (*Bacillus phytophthorus*).—By the middle of June affected plants may be detected by their yellowish colour. The base of the stem is blackened and decayed and the stalks are easily pulled away. Later in the season the young tubers become more or less affected, especially at the heel end. Decay continues and spreads during storage, and if slightly diseased tubers are planted they give rise to diseased plants. Blackleg may be kept in check by planting only healthy seed, and it may pay to dig and destroy affected plants. It has been observed that the following varieties are rather susceptible to the disease: Kerr's Pink, British Queen, Arran Consul, Great Scot, King Edward VII, Majestic, Rhoderick Dhu, Duke of York, Epicure, and Eclipse.

(*b*) **Potato Disease or "Blight"** (*Phytophthora infestans*).—This is the worst scourge of the potato crop ; not only does the fungus attack the foliage of the plant and cause it to decay and die off prematurely, but the disease finds its way through the soil to the tubers, which develop dark-coloured sunken areas on the surface and brown rot below the skin. The disease extends until the whole tuber has suffered a dry rot, but secondary organisms may later on convert this into a wet rot. Affected potatoes have to

be discarded as soon as they are lifted, and spores of the fungus, present on seemingly unaffected tubers at lifting time, cause the potatoes to become diseased during the period of storage. As far as is known the disease is chiefly carried from one season to the next in the tuber and the first spores come from the foliage of affected plants.

The outward manifestation of the disease on growing potatoes is a browning and dying-off of a portion of the leaf tissue, and if the under-surface of an affected lamina is examined the presence of the spore-bearing conidia can be observed round the dead tissue. The affection starts in June, July, or August, and is most severe during periods of warm, damp, and misty weather, which facilitates the germination of the reproductive spores on healthy plants and thus enables the disease to propagate rapidly.

As mentioned earlier (p. 333), the only effective preventive measure is to treat the plants with a fungicidal spray. The disease can be prevented to some extent, however, by a very careful selection of seed, taking care to exclude all sets that exhibit the minutest trace of infection: this inspection, of course, can best be performed when the seed is sprouting in boxes. Spread of infection from a small focus may be prevented by spraying the diseased plants with sulphuric acid.[1] None of the established varieties can resist attack to the foliage, but the degree of resistance to tuber infection varies widely and in some varieties is quite high. In all cases thorough earthing-up of the rows is helpful, because a good layer of soil filters the percolating rain and prevents the spores, washed off the foliage, from reaching the tubers.

It is now known that there are four distinct strains of the blight fungus, but one or other of the wild species of *Solanum* possesses complete immunity to each. New techniques in plant breeding enable these wild species to be intercrossed with cultivated varieties, and a number of seedlings, produced by hybridization with these forms, have been found to possess the desirable four-fold immunity. There is thus considerable hope that completely immune sorts, possessing the various other desirable characters, will be made available within the next few years.

Murphy's experiments in Ireland demonstrated that potatoes which are dug while the stalks are blighted, but still living, are

[1] The earliest infection is often found in the sites of the previous year's clamps. Good results have been obtained in America by the systematic destruction of plants growing on such places.

practically sure to develop blight during storage, and it was concluded that a large proportion of such tubers became infected during digging operations from contact with blighted foliage or contaminated surface soil. The inference from these experiments is that either the crop should be lifted before it is seriously blighted or, alternatively, be left for about a fortnight after the haulms are dead, when the spores will have lost their virulence. The former course is the better and should be adopted when practicable, as in the case of early varieties. The latter course involves the risk that in spite of the precaution the infection may reach the tubers through the soil; but this risk may not be serious where the potatoes are well covered with close-textured earth. Measures to prevent infection of the tubers (haulm destruction) are described on page 336.

The problem of disposing of a highly infected crop has to be considered by the practical man. It is dangerous to feed the tubers to stock unless after cooking, because infective material may be carried to the next crop in the manure. The best plan is to dispose of the seed and chats together as "pig potatoes" to a farmer who does not go in for potato-growing. The picked ware can, of course, be sold in the usual way, but it is advisable to sell it immediately, even if a lower price has to be accepted, because if it remains in store the disease develops so rapidly on the affected tubers that in a few months' time little or no marketable produce may be left. If potatoes are lifted for marketing when the leaves are blighted, and if the seconds are to be reserved for seed, the latter may be disinfected by dipping in a dilute solution of formaldehyde or other fungicide.

E. Disease affecting the whole plant but not destroying the tubers:—

Verticillium Wilt (*Verticillium albo-atrum*).—This fungus more or less blocks up the water-channels in the plant, thereby causing the leaves to become limp or to wilt. The haulms die prematurely and the development of the tubers is checked. The fungus passes into the young potatoes through the underground stems, and if such potatoes are planted they will give rise to a diseased crop. The remedy is to buy in healthy seed.

F. Diseases which affect the whole plant but do not cause decay:—

Virus Diseases.—It was formerly believed that potato stocks underwent a natural process of degeneration, and that, no matter

how good the variety might be for a few years, it would ultimately have to be discarded owing to old age. It is now known, however, that deterioration is brought about by virus diseases such as Leaf Roll and Mosaic. Virus X is transmitted from affected to neighbouring plants by contact—*i.e.* by the rubbing together of the foliage. The others that are responsible for mosaic and also that of leaf roll are transmitted by insect "vectors." The insect mainly responsible, at least in Scotland, is the green-fly *Myzus persicae*, which overwinters mainly on swedes, kale, savoys, and other brassicas. In late spring or early summer the winged forms migrate to potato fields and carry the infection with them. The spread of virus disease thus depends largely on the aphid population, which varies greatly from one district to another. There are large areas in Scotland and Northern Ireland and smaller ones in England and Wales where the aphid population is generally small and where, therefore, with due precautions, infection can be kept at a low level. There is, however, a considerable year-to-year variation in numbers of aphids. In some particular upland areas and in certain of the Scottish Western Isles aphids seem to be absent. A stock suffering slightly from the effects of one virus may have its condition greatly worsened through infection by one or more other viruses. The diseases are perpetuated through the tubers and there is no chance of recovery; indeed it is quite normal for the number of diseased plants to be trebled from year to year. The effect on the yield depends on the severity of the attack and the susceptibility of the variety, but it is not unusual for leaf roll, mild mosaic, and severe mosaic to cause reductions of the order of from 40 to over 90, 20 to 40, and 40 to 75 per cent. respectively. When both leaf roll and severe mosaic affect a plant the result is devastating. In some cases the symptoms of virus infection, apart from a decline in yield, are so slight as to be imperceptible to the eye. In certain cases, too, infection with any one of two viruses may have but little effect; yet when the one is superimposed on the other the effect on the plant may be very severe.

Leaf roll is caused by a single virus which in the year of infection may produce no visible symptoms or, if introduced early enough, may cause a condition known as *Primary Leaf Roll* that is characterized by slight curling and stiffening of some of the leaves. In the following year plants from affected tubers develop *Secondary Leaf Roll*, which takes the form of a

hardening of the leaves, an upward and inward rolling of the leaf margins, and a general stiffening and stunting of the shaws. The visible symptoms arise from damage to and blocking of the phloem tissue and consequent interference with the transfer of starch from the leaves to the tubers. No known species of *Solanum*, whether cultivated or wild, appears to be immune.

Mosaic in its various forms is caused principally by three viruses, designated X, Y, and A, which invade the plant singly or in different combinations. *Negligible Mottle* is usually caused by mild strains of X or by A. In *Mild Mosaic*, which is normally caused by virus X but also occasionally by A in combination with mild strains of X, there is a mottling of the leaves in shades of light and dark green, or even yellow and green, but no wrinkling of the leaves or reduction in their size. In *Rugose* or *Severe Mosaic*, caused by the combination of A with severer strains of X, or by Y alone or in combination with A or X, mottling is also present but is accompanied by a wrinkling or distortion of the leaves and a dwarfing of the whole plant. In extreme forms, as for instance in Majestic, the affected leaves die prematurely and hang by a thin thread to the stem. This condition has been called *Leaf-drop Streak*, but it is due to the same causes as typical rugose mosaic. With virus diseases the degree of severity actually ranges from a mottling so slight that it can barely be noticed, through increasingly diseased conditions, to the most marked mottling, distortion, and stunting of the plants.

As knowledge is accumulated it may be possible to help limit the spread of virus disease by planned planting. For instance, a variety that carries X without apparent ill-effects but suffers from severe mosaic when A is superimposed, obviously should not be planted alongside a variety that is known to be infected with the latter virus. The ultimate solution of the virus problem may probably be found in the production of field-immune or immune varieties.

Apart from infection with virus disease, potatoes may develop degenerate forms which have been termed respectively Bolters and Wildings. A bolter possesses abnormally tall, open, and vigorous foliage and usually has a very free flowering habit; it is late in maturing. A wilding has an abnormally bushy habit of growth and develops an exceptionally large number of thin branches; it produces a very large number of small tubers. Both the bolter and wilding conditions are now believed to be

due to chromosome abnormalities and are perpetuated through the tubers, so that the only means of eliminating either is by thoroughly roguing the seed crop (see p. 319).

PESTS

Potatoes are not much parasitized by insects, but are attacked to some extent by the Death's-Head moth and, in other countries, the Colorado beetle. Aphids, "leather jackets," wireworms, and slugs are, of course, destructive.

Aphids.—The peach-potato aphids winter on brassicas and in summer migrate to the potato crop. The insects transmit virus diseases and in a warm, dry season may become so numerous that they destroy the foliage; but cold and wet weather retard their increase. A dangerous attack may be controlled by spraying with nicotine sulphate, 8 to 10 oz., added to Bordeaux mixture, 50 gals., or by applying a proprietary nicotine or TEPP preparation.

Colorado Beetle.—There have been several outbreaks of the pest in southern England and there is danger that it may become established in Britain. The standard method of control is to add calcium arsenate, or a suitable arsenical compound or DDT, to the copper dust or spray employed as a preventive for blight. In some cases, however, the beetles become numerous before the ordinary time for spraying against blight, in which case a special application of insecticide becomes necessary.

Root Eelworm.—When potatoes are grown year after year on the same ground they may be seriously attacked by eelworms. The species, formerly thought to be a strain of the same species as the beet eelworm, is now known to be a separate species. Once established in the soil, the parasites spread from year to year in ever-widening circles, and the yield of the attacked crop is reduced to quite an unremunerative level. Diseased patches may be detected by the stunted growth and sickly colour of the foliage and the withering of the lower leaves, which gives the heads of the plants a tufted appearance. Examination of the roots confirms the nature of the attack, for there can be found the bodies of the females, in all stages of development, protruding from the cortex. At first the bodies are white and pear-shaped, but after fertilization they swell up and change into brown resting cysts, each containing 250 to 300 eggs or larvæ, and having the

appearance of poppy seed. The cysts are loosely attached to the roots and break off when the crop is lifted; they remain dormant in the soil until potatoes are again planted. Soon after the growth of the next crop begins the larvæ hatch and bore into the potato roots, thereby damaging the tissues, interfering with the water supply of the plant, and reproducing the symptoms of the disease. An important aspect of the disease is that its presence greatly depreciates the value of the land.

The infection of clean ground is most likely to be brought about by introducing the cysts in purchased seed. It has been shown, however, that some land has been infected through the barrels used for marketing early crops, and also by the purchase of cabbage or other plants grown on infected soil. If containers have been used for infected potatoes, the soil and rubbish in them is full of cysts, and if this material is emptied out on another field the disease will obviously be introduced. Early potatoes suffer less than maincrops because the crop is lifted while a large proportion of the cysts are still immature. The only certain method of control is to withhold potatoes from the infected soil for a considerable period. In some cases four years seems to be adequate, but in others considerable numbers of cysts survive much longer.

The eggs of the eelworm normally remain dormant in the soil until potatoes are planted, and it has been shown that hatching is induced by a substance secreted by the potato roots. Research is at present being directed to determine the nature of this secretion, and to discover some chemical that might have the same effect. If hatching could be induced in the absence of a potato crop the larvæ would quickly die and complete control would be secured. Another approach is to apply some material which would mask the effect of the substance that induces hatching. Mustard oil has been shown to have some slight effect of this kind. Soil sterilization is, of course, effective against soil nematodes and is employed in the case of glass-house soils. Fumigation is a possibility with small areas, and the dichlorpropanes (including that sold as "D.D.") are the most effective compounds for the purpose. Field experiments with D.D. have shown that the material has a beneficial effect, but the cost is high. So far it is only in Jersey (where potatoes and tomato crops are grown in succession each year) that the treatment has been used commercially. Other materials were under investigation at the time of writing.

A possible long-term solution is the production of commercial varieties with an immune wild species (*Solanum andigenum*) as one of the parents.

Wild species of *Solanum* (the nightshades) are sometimes found to be slightly infected. The only other crop host is the tomato.

Another species, the potato tuber eelworm, is widely distributed but of comparatively small economic importance.

Wireworms damage potatoes by riddling the tubers with holes and in bad cases rendering them unsaleable. Where the pests are numerous, damage may often be minimized by growing an early or second-early variety in preference to a maincrop or late. The reason is that the wireworm has two main feeding periods, viz. from March till June and from September until the onset of winter cold. Thus if the crop is lifted by late August the second attack will normally not have taken place and the tubers will be undamaged. The feeding seasons are indeed most clearly defined in the warmer and drier parts of the country and in the drier and hotter years, the insects burrowing in the hot summer months into the subsoil to escape desiccation. Hence under wet and cool conditions even early potatoes may suffer severe damage. Wherever a maincrop is exposed to attack it should be lifted as early as possible. As previously mentioned (see p. 274), there is now good evidence that wireworm population can be reduced by the use of soil insecticides. Benzene hexachloride, however, may impart a taint to potatoes and root vegetables. Other materials, free from this objection, seemed promising at the time of writing.

CHAPTER IV

THE ROOT CROPS

TURNIPS AND SWEDES

TURNIPS and swedes are biennial plants belonging to the cruciferous genus *Brassica*: they are termed "roots," but the fleshy portions are in fact enlarged hypocotyls and contain but little true root tissue. Their habit is to store up large quantities of food material in the first year of their growth and to develop their reproductive parts and to ripen their seed in the second season. The species that do not develop swollen hypocotyls are known as rapes, and are grown for seed production and for soiling or folding.

Turnips and swedes form our most widely cultivated root crop, especially in the northern and more humid regions. It is commonly but wrongly believed that the turnip was brought to Britain about the time of the origination of the Norfolk rotation, and that it is therefore a comparatively recent introduction; in reality it was cultivated in gardens at a much earlier period. During the early days of field cultivation turnips were sown broadcast, but about the end of the eighteenth century drilling on ridges began to be common. About thirty years later a new sort, possessing distinct characteristics, was introduced from the Continent and called a Swede, after the country of its origin. Turnips and swedes increased rapidly in popularity as soon as the system of drill cultivation had been established, as up to this time the only means of bringing foul land back to a state of cleanliness and fertility was to turn it over to bare fallow. Turnips grown in drills, however, permitted cleaning operations and avoided the waste and expense due to the want of a crop.

Root crops are grown with the primary object of producing winter food for stock, and differ from potatoes in being almost universally consumed on the holding, thus conserving the soil fertility. They also, as mentioned above, form a most important cleaning crop in a great many rotations. The food value of turnips is high—not weight for weight with other foods, but in proportion

to the dry-matter content. In its nature the turnip is not comparable to a roughage like straw or hay, because its bulk consists not of indigestible fibre but of water. The great advantage of roots, of course, is that they provide a palatable form succulent food at a time of the year when no other may be available. When fed to cattle their slightly laxative qualities balance the binding effect of dry fodder such as straw. Some proportion of the turnip crop is eaten off by sheep, and some light-land farmers still maintain that without their turnip-fed sheep they could not keep their farms under the plough. Folding is unsuitable for heavy land, as it would cause puddling.

Varieties.—Those sorts of turnips and swedes which produce the highest yield per acre, and at the same time have a high feeding value, are the most valuable. The dry-matter content of different varieties varies very considerably, and the heaviest yielder is not necessarily the most productive of dry matter. In the absence of more precise knowledge, however, it may be assumed that the feeding value of the roots is proportional to their dry-matter content. Quality, which is largely a matter of dry-matter content, is of great importance, and in the selection of newer and better kinds analyses should be made from time to time to ascertain the composition. Quality is also influenced to some extent by manuring, since by heavy applications of nitrogen it is possible to force the roots to a great size; but the extra weight is mostly water, and susceptibility to frost damage is increased. The following are other points that should be considered in variety selection: The seedling should grow and develop its root system rapidly, as there is a great danger of the plant becoming dried out before it reaches the rough-leaf stage; there should be sufficient foliage to provide cover and protection from frost; the bulbs should grow well out of the ground to facilitate lifting, and, lastly, the capacity to resist disease should be high, as, other things being equal, a disease-resisting sort will produce a very superior yield in case of an attack.

Turnips and swedes are cross-fertilized plants and even the common varieties show such a marked tendency to variation that it is only by very careful selection of mother-roots that they can be kept reasonably true to type. In actual practice seedsmen may have different ideas as to what represents the best shape, colour, etc., of a given variety, and if they make their selection from the same stock the result will be that a number of different types

appear on the market under the same name. In fact, this state of affairs has so far made an accurate classification of turnips impossible. Although certain commonly recognized types of swedes and turnips are described below, it should be clearly understood that, for reasons stated above, there are many varieties having characteristics that are not in accordance with the grouping.

Swedes.—These can at once be recognized by their glaucous leaves, which also differ from the rough-looking foliage of the turnip in having no hairs and in arising from a neck or stumpy stem. The colour of the flesh is normally yellow, but white-fleshed swedes are known. The swede is harder than the turnip, has a better feeding value, and is sweeter to the taste. Swedes require better soil and treatment than is necessary for turnips, and although they do not mature so rapidly, they withstand frost much better and keep longer. They should not be fed to stock while they are immature, as in this state they are apt to cause digestive disorders, but should be consumed after the ordinary turnips have been used up.

Swedes are ordinarily classified according to the colour of the skin, as green-top, purple-top, and bronze-top. The green-skinned group embraces two types, the Wilhelmsburger and the Wintergreen. Both have small tops and necks, and both are highly frost-resistant.

The dark-purple-skinned types are also, with very few exceptions, highly resistant to damage by frost. The gross yield is rather below average, but many of the particular varieties show a relatively high dry-matter content, so that the yield expressed in terms of dry matter is high. As in other groups, the particular shape of a variety seems to be unrelated to frost resistance or nutritional value.

Many of the varieties with light-purple skin are low in dry-matter content and rather susceptible to frost damage.

The bronze-skin type owe their colour to a mixture of green and purple pigment. The colour is not constant even in carefully selected varieties, varying from purple-bronze to greenish bronze. Bronze-top varieties vary widely in dry-matter content, frost resistance, and other agricultural characteristics.

Varieties of swedes are very numerous, most of the larger seed houses having their own selections. Moreover, since swedes are cross-pollinated in the field, varietal characteristics are difficult to fix, and the actual material that is sold under a particular name varies according to the standards of selection adopted by the

particular seedsman. There is thus little point in listing the varieties by name. One important point, however, is that considerable success has been attained in selecting for resistance to "finger-and-toe" disease. Wilhelmsburger is the best known of the highly resistant varieties.

Turnips.—The foliage is pale green, and the lyrate leaves, which are covered with hairs giving them a rough appearance, spring from the top of the " root " in a rosette. Some varieties have elongated bulbs, the greater part of which is above ground-level, while some are short and globe-shaped, and others are intermediate. They may be white, any shade of green or purple, or mottled; but the colour has no special significance. Turnips have a much shorter growing season than swedes, and, indeed, can be grown as a catch crop after harvest in early districts: this quick maturity allows them to be fed early without endangering the stock; indeed, early feeding is necessary as they neither withstand frost nor keep well. Turnips, in relation to the length of their growing season, yield more total weight per acre than swedes, but are inferior in feeding value; they have about 5 per cent. more foliage than swedes, the proportion of root to top being about 5 to 1.

The following are the three principal classes of turnips:—

1. *White Turnips.*—These contain only 7½ to 8 per cent. dry matter and, although the heaviest croppers, are of the poorest feeding value. They can be grown on the poorest of soil; they are often sown to fill up headlands and fed with their leaves to stock on the grass towards the end of summer, or they may be broadcast after harvest to form a catch crop; their keeping quality and frost-resisting power are very low. One of their greatest advantages is that they will crop well even when sown late. Two well-known varieties of this class are Greystone and White Globe.

2. *Soft Yellows* are intermediate in quality between whites and yellows, and contain 8½ to 9 per cent. dry matter. Fosterton's Hybrid and Early Sheep Fold are of this type.

3. *Hardy Yellow Turnips*, of which the Aberdeen Yellow is the best known, are about as good as swedes in keeping quality and feeding value; they contain approximately 10½ per cent. dry matter, and are very hardy and frost-resistant. The Bruce variety, which is highly resistant to " finger-and-toe " disease, belongs to this group.

CULTIVATION

Soil and Climate.—Turnips and swedes are the typical roots of Scotland, Ireland, and the north and west of England; but they were formerly largely grown on the poor, thin soils of the chalk and oölite regions. The crop, like oats, attains its highest perfection in cool and fairly moist climates; when grown under dry conditions the yield is very low. Turnips thrive better than mangolds in an absence of sunshine, and their shallow root systems render them liable to be dried out in districts of low rainfall.

The acreage of both turnips and swedes in the south-eastern half of England has greatly declined in recent years. This is in part a result of the increased cultivation of sugar-beet, in part a reflection of the high labour requirements of the crop, and in part due to the greater use of fertilizers and the lesser emphasis on the need for folded sheep and yarded cattle as means of maintaining soil fertility.

The most suitable soils are those of the lighter class, as on heavy land it is difficult to get the required fineness of tilth for the germination of the small seed, and the fine rootlets do not grow so well through the close texture.

Place in Rotation.—In most cases roots form the chief cleaning crop of the rotation, the cleaning operations commencing before seed time and going on throughout the period of growth. As is to be expected then, roots are taken between two straw crops, but they cannot easily be taken before autumn-sown wheat, since it is difficult to get them off the land in time. The frequency with which turnip crops may recur on the same ground depends largely on the risk of "finger-and-toe" disease, but the interval is rarely less than four years, and may be seven or more in districts where the soil is poor in lime and the disease is more insidious.

Preparation and Sowing.—The soil for turnips receives a more complete and thorough preparation than is the case for any other crop in the rotation. This is possible because turnips are sown comparatively late and at a time when most of the labour of the farm is freed from the other spring operations, and is necessary because of the very fine tilth required for germination and growth. The land must also be cleaned of weeds which would compete with the struggling plants in their young stages, and it is usual to drag out and burn any twitch or other root weeds. As in the management of the potato crop, the sequence of operations varies

according as the dung is applied in autumn or in spring. When spring dunging is intended the land is ploughed as deeply as possible in autumn to bury the surface weeds, to facilitate aeration and drainage, and to allow the soil to benefit by the action of frost. In spring it may be desirable to plough again, but if there is a danger of losing the frost mould and bringing up clods, this will have to be done early enough to secure a further period of weathering. On foul land more than one spring ploughing may be given, each being followed by a dragging to fetch the weeds to the surface, so that they can be rolled up with chain harrows, collected, and removed to a compost heap or burned. The fine mould for the seed-bed is normally prepared by a series of cultivations, harrowings, and rollings. Two important points should always be borne in mind when preparing turnip land: the first is the danger of over-cultivation, resulting in the drying out of the surface layers and a consequent failure of the seeds to germinate; the second is the importance of seizing every opportunity to gain the required tilth with a minimum of operations, which is best done by taking advantage of every fall of rain to work the clods when they are most easily broken, *i.e.* when they are in a half-wet, half-dry condition. When the desired tilth has been obtained, the land is, in many districts, ridged as for potatoes, well-rotted muck is spread in the furrows, the artificial manures are broadcast, the ridges are split to cover the manures, and the land is ready for seeding. In the preparation of turnip ridges the ordinary double-mould-board plough does not give the best results, as it has a pushing action and tends to leave the clods and coarse particles of soil on the tops of the ridges where the seed is to be sown, and the dry surface layer in the middle of the ridge under the seed. An ordinary plough in the hands of a capable workman can do better work by rolling the clods to the bottom, digging up the fine, damp, pulverized soil, and leaving it where it is most required by the delicate seedlings.

In northern and western districts the crop is grown on ridges which average about 27 in. in breadth. It is claimed that ridging, in addition to facilitating horse-hoeing, gathers the fine soil under the plants so that they develop their roots easily and begin active growth quickly; it also means that artificial manures are gathered near the roots where they are most required, hand-hoeing and singling can be done cheaply, and the plants suffer less injury in the process than when the crop is grown on the flat.

In many of the dry districts of England turnips are sown on the flat, in drills 18 to 20 in. apart, because it is held that the extra surface exposed when ridges are made allows the soil to become so dry that the crop cannot thrive. Many authorities recommend that wherever the annual rainfall is less than 24 in., or where the soil is specially liable to dry out, this method should be followed. On clean land, sowing on the flat is perfectly satisfactory, but if the land is weedy and the turnips receive any check in their early growth, the weeds may spring up to such an extent that it is almost impossible to pick out the drills, horse-hoeing is delayed, and the turnips may be choked out altogether.

As a rule swedes are sown between the beginning and the end of May, and turnips about a fortnight later; but on thin soils in hot, dry districts, such as the chalk and oölite regions in the south of England, where mildew is apt seriously to affect the early sown crops, seeding does not commence until the last week of June. The incidence of mildew is an important deterrant to turnip and swede growing in the drier areas. In some localities turnips and swedes are often regarded as a "half crop," foul land being fallowed throughout May and June and the seed sown in July. The roots in such a case are naturally small, but they resist frost well and are useful for sheep feeding in late winter. On the other hand, swede sowing may occasionally commence in April. Crops that are sown too early tend to "bolt," turnips being worse than swedes in this respect. It is advisable to allow short intervals between the sowings, and to sow only a few acres at a time, so that the whole area will not reach the singling stage simultaneously.

The average seed rate is 3 lb. per acre for turnips and 4 lb. per acre for swedes. Where a good tilth has been prepared, thin sowing allows the plants to grow quickly and makes them easy to thin, but where turnip fly is apt to be injurious, a thick seeding should be given to ensure that all the plants will not be destroyed. A relatively heavy seeding is also used on heavy land or where sowing is abnormally early. In the former case the unsuitable nature of the tilth will lead to diminished germination, and in the latter a high mortality among the seedlings must be expected.

The machines used for ridge sowing take two drills at a time, and are fitted with rollers to pack the soil about the seed and to enable the rootlets easily to get their water supply; but many light-land farmers like to follow up the drill with a light roller so as further to increase this consolidation. The machines used for

drilling on the flat sow four rows at a time, and sometimes water drills are used which deposit a certain amount of water with the seed.

Manuring.—Although turnips can be successfully grown with artificial manures alone, they are so dependent on the texture and the moisture-content of the soil that farmyard manure should be applied whenever it is available. It is useless to attempt to grow turnips without manure of some sort, as no crop is more quickly affected by soil poverty. If necessary, of course, artificial manures may be used alone, and indeed in some rotations most of the dung is used for the potato, sugar-beet, or mangold crops, and it is impossible to make an allotment to all the roots grown. Even when a good quantity of muck is available, the best results will be got by supplementing this with suitable artificials. With roots, as with other crops, the presence or absence of dung makes little difference to the crop's response to dressings of inorganic nitrogen, but on dunged land the need for phosphatic and potassic fertilizers is greatly reduced. Of course excessive nitrogenous manure tends to make the roots watery, more susceptible to disease and frost, and of poorer keeping quality. The phosphatic fertilizers are important for turnips as phosphates frequently form the limiting factor in the yield. The optimal quantity depends on the soil, and, as with other crops, heavier dressings are often desirable in the wetter west and in the north. The normal amount is from 4 to 6 cwt. of superphosphate per acre, or an equivalent of bone-flour or basic slag in light and heavy land respectively, in addition to a moderate dressing of dung. This produces during the seedling stage a remarkably rapid growth, which is of great advantage to a crop of the nature of turnips. Ground mineral phosphate gives good results on some of the more acid soils in the cooler and wetter areas, especially in Scotland, but should not be used on a field scale without preliminary small-scale trials. Sometimes potash is not used along with dung.

A suitable manuring for average conditions would be 14 tons of dung, 5 cwt. of superphosphate, 1 cwt. of muriate of potash, and 2 to 3 cwt. of sulphate of ammonia. Unlike beet and mangolds, the crop does not ordinarily respond to sodium salts. When no dung is available, 6 to 9 cwt. of superphosphate, 2 to 3 cwt. of sulphate of ammonia, and 1½ to 2 cwt. of muriate of potash should be applied. The nitrogen dressing should generally be reduced—in some cases to 1 cwt.—for crops that are likely to

be exposed to winter frosts, or where resistance to disease and keeping quality are of more importance than yield. The best results are got when the placement of the fertilizer is close to the rows of plants but not in contact with the seed.

Concerning the time and manner of applying the farmyard manure there is a considerable difference of opinion. On the light class of soils it is perhaps better to spread it in the autumn and plough it in immediately, as this greatly increases the capacity of the soil for water, and may result in a satisfactory crop when other land that has received no dung contains too little moisture to swell the seed and promote germination. If it is found necessary to manure in the drills in spring, the dung should be short and well rotted so that it will not interfere with the supply of soil water. If the only available manure is long and unrotted, it should be turned over so that it may ferment and break down, even though a loss of nitrogen is occasioned thereby.

Subsequent Cultivations.—Usually the first implement that is used when the plants have appeared through the ground is a side-hoe, which pares down the ridges to some extent and greatly facilitates the task of singling; but a scuffler may also be used for this purpose. In an average season the plants are in rough leaf about three weeks after sowing and then the sooner they are singled the better. The usual distance to which turnips are singled is 9 in., but it may be anything from 6 to 12 in., depending on the fertility of the soil and the habit of growth of the variety. Singling is usually carried out with a hand-hoe, but in some districts where small acreages are grown it is performed entirely by hand, or the hoe may be used only to give a preliminary bunching. Machines are on the market which bunch the plants to any desired interval, and make singling a less lengthy and less costly process. Whichever method is employed it is of the utmost importance that the work should be carefully and thoroughly done, as the yield of the crop can be greatly reduced by carelessness. Unless trustworthy and skilled labourers can be secured, it is not advisable to have singling done by piece-work. When the workers are going over the ground they should be instructed to strike out all weeds that have established themselves between the rows. In order to save the cost, some poor-land farmers who intend to feed the roots off with sheep do not single the plants, but reduce their numbers by dragging a cultivator across the drills.

When singling is over the plants are kept free from weeds, and

the soil well aerated, by hand-hoeing and by a series of drill cultivations, until the foliage is so large that it is liable to be damaged. Sometimes the crop is lightly ridged up before it is left, in order to assist surface drainage; but on light soil it is questionable if the operation has any advantage.

Lifting Turnips and Swedes.—In a mild season some varieties of roots go on growing right up to New Year, but when the outer leaves fall away the crop may be considered as mature and may be removed when it is required. At this stage, or a little earlier, the dry-matter yield is at its maximum, for thereafter the leaves fail to make good the losses due to respiration. Turnips are usually pulled by hand. They may be fed together with their leaves as long as the latter are green and fresh, but unless they come out of the ground very free from dirt the roots are struck off with a turnip knife. Later in the season when the tops are partly decayed, or when the turnips are to be stored in bulk, the crop is both topped and tailed. The lifter deals with two drills at a time and leaves the produce of four drills in one row so as to provide passage for a cart and facilitate loading. Turnips can also be topped, tailed, and lifted by means of a horse-drawn root-lifter. The implement may do the job rather roughly but it is a useful standby when hand labour is short. White turnips, which are usually grown in small quantities only, are generally fed with their tops to animals on the grass in September, or they may be fed off with sheep. Yellow turnips are ready for use in October and swedes about the end of November. From November onwards it is the custom in most districts to remove the turnips from the land and store them for winter feeding; but they may be treated in any of the following ways:—

1. In mild districts, and where the crop is grown near the sea, the hardier sorts of swedes and even of turnips may stand out all winter and be removed when required. They may also be allowed to stand out in poor districts where the roots are small and hard, and are hence not liable to injury by frost.

2. The turnips may be left growing in the fields and fed off as they stand on the ground. When one part of the crop is folded and the remainder is carted off, it is worth removing the roots from strips at regular intervals over the field. This ensures that the droppings of the sheep consuming the remaining roots will be distributed evenly over the ground.

3. They may be stored in small clamps, containing about four

to six loads each, which are distributed over the turnip field or on a stubble, and roughly covered to protect them until they are sliced for sheep-feeding in the winter months.

4. Turnips or swedes, especially the latter, may be protected in the field by ploughing them in. This is done by ploughing out a furrow, lifting two rows and placing the roots in the bottom, and then ploughing the soil back to give them a good covering. Roots stored in this way probably keep better than when they are preserved in any other manner; but when they are ploughed out for use a good deal of time may be required to clean them.

5. The most usual method of storing, however, is to cart the roots to a suitable spot in the vicinity of the feeding sheds and place them in long, broad clamps, well covered with straw to protect them from frost.

In all cases where the bulk of the crop is allowed to remain in the fields during winter, it is necessary to keep a supply in the farm buildings which will be sufficient for the wants of the animals during any ordinary spell of hard weather.

Yield.—The average yield of turnips for the whole country is about 14 tons per acre; but in the typical turnip districts of the north 20 to 25 tons can easily be grown, and, on the other hand, 10 to 12 tons is an average crop on some thin soils.

GROWING TURNIP SEED

Instead of purchasing turnip seed it is an easy matter to grow all that is required for use on the farm. To do this, good, solid, shapely mother-roots, which are entirely free from disease, should be selected and transplanted to a sheltered spot, giving each plant about a square yard of ground, so that they will remain in good condition throughout the winter. The site should be several hundred yards from any garden or waste ground where other brassicas might flower at the same time as the turnips and thus cause cross-fertilization. Shooting takes place early in the following season, and it is helpful to remove some of the small top branches so that every chance is given for the production of good, large seed. The ripening seed may have to be protected from birds by means of netting on a suitable framework. The shoots should be cut as soon as they are ripe and stored in an airy shed until they are dry and brittle. When threshing has taken place the seed should be passed over a riddle and the small specimens discarded, as it has

been shown that the largest seeds produce the biggest and most robust plants. Before storing, the seed should be dipped in paraffin to protect it from insect attacks.

The ordinary routine adopted by seedsmen is to broadcast, in late summer or early autumn, "stock" seed obtained from selected bulbs, the early sowing causing the resulting crop to "run to seed" in the following year. Commercial crops thus represent the second generation from the selected plant. Commercial seed is grown chiefly in the eastern and south-eastern counties of England. Average yields are about 8 cwt. for turnips and 6 cwt. for swedes, but the seasonal variation is extremely wide.

FUNGOID DISEASES

"**Finger-and-Toe.**"—This disease is due to the attack of a slime fungus which finds its way into the growing root tissue from the soil. At first the affected plant is unthrifty in appearance and its leaves are somewhat wilted. An examination of the root reveals the chief characteristic of the disease—the presence of malformations or "club roots" due to the stimulating action of the fungus which multiplies rapidly within the cells. The root is stunted and small and afterwards decays.

The longevity of the fungus makes it difficult to deal with; but it is found to be most persistent on land that is definitely sour. An ordinary degree of acidity can be remedied by applying 30 cwt. to 2 tons of slaked lime per acre, the influence of such dressings on the activity of the organism being most marked when they are applied in the autumn six or eighteen months before the turnips are to be sown. In certain cases such a dressing may immobilize the boron in the soil and so induce the condition known as heart-rot, brown-heart, or raan, which is due to boron deficiency. It can be prevented by making a small application of borax (see p. 388). When it is practicable to lengthen the rotation or to put the worst infected fields down to grass for a period, the fungus is either eradicated or its activity greatly reduced. Only it must be remembered that the land will be re-infected if diseased roots are thrown out on the grass for feeding. A point that should never be overlooked when turnips have to be grown on badly infected soil is the selection of varieties that are resistant to the disease. It is possible to obtain varieties—*e.g.* The Bruce turnip and the Wilhelmsburger swede—that are affected only to a slight degree.

It is, of course, recommended that cruciferous weeds should be suppressed, and the dung containing the remains of diseased roots should not be used for turnips; but these precautions are difficult to carry out in practice.

Turnip Mildew.—A number of species of leaf mildew attack the leaves of turnips and other cruciferous plants, the greatest damage being sustained in the southern counties, where the growth of the crop is apt to be retarded by hot and dry weather.

In southern districts turnips are sown a month later than in other places, because they are then found to suffer less than when early sowing has brought about a considerable development of foliage by the time the hottest and driest season is reached. If seedling turnips are found to be affected they should be singled at once, so that each plant may have room to develop and the competition for the available soil moisture may be reduced.

Other Diseases.—Crown and Root Rots (*B. caratovorus*) and Dry Rot (*Phoma lingam*) are other diseases which greatly affect the proportion of usable roots in the crop. At present the only way to deal with them is to secure varieties that have some resistance to their attack.

INSECT PESTS

The Turnip "Fly" (flea-beetles).—These insects are readily recognized by the swift and long jumps that they make when disturbed. The beetle is only about $\frac{1}{10}$ in. long, and the commonest species is readily recognizable by the broad yellow band running down each wing cover, but other species are respectively bluish black and black all over. The period of greatest activity is from about late April to mid-May, but this varies somewhat with the locality and the season. The eggs are laid from May to July in the soil near a host plant, and five or six weeks later, after the larvæ have fed and pupated, the adults emerge. The young beetles are active until September and hibernate in sheltered places over winter; they do not lay their eggs until the following summer. Thus there is only one generation per year, but two generations may co-exist for a time in late summer. The damage is caused not by the larvæ but by the adult beetles which attack the delicate seed leaves of the turnips and related species as soon as or even before they are through the ground. In a season when growth is slow the plants may be eaten off altogether. When the plants have reached the rough-leaf

stage they may be considered safe, but it is sometimes necessary to sow the crop several times before it can establish itself. In some cases it is possible to escape serious damage by choosing the time of sowing with regard to the known time of maximum fly activity in the district. Thus kale sown in March (which is generally possible in the south), may be established before the fly becomes active, and a late sowing in mid-May will also generally escape the worst.

Control can be effected by dusting the seedlings (or the surface of the ground before the seedlings break through) with a suitable material. Derris, nicotine, and nicotine sulphate were formerly among the most effective materials, but dusts containing D.D.T. or benzene hexachloride have recently been shown to be much better, mainly because they remain effective over a much longer period. Dusts are best applied by means of a special machine, but quite good distribution can be got from a grass-seed barrow or, on a small scale, by jerking cheese-cloth or muslin bags of dust over the plants. Dust raised by driving a flock of sheep over the dry ground or applied in the form of slaked lime does not destroy the beetles but has a certain deterrent effect and so protects the leaves. It may also help to keep the beetles away if the seed is soaked in turpentine or paraffin before sowing. As charlock and related weeds are host plants it is obviously helpful to adopt a system of weed destruction which will keep them under control. It should be noted that an attack may begin before the seedlings have actually appeared, and it is therefore most important that watch be started before the seed leaves emerge.

Other insects that attack turnips are surface caterpillars, the silver Y-moth, the turnip mud beetle, the turnip gall weevil, the diamond-back moth and the turnip root fly ; the swede midge ; the mealy cabbage aphid and the peach-potato aphid.

MANGOLDS AND FODDER BEET

Mangolds are supposed to have been evolved by a long process of careful selection from the wild sea-beet, which is still found in many temperate districts. The mangold, which is of German origin, was introduced to this country in 1786 but was little grown until about 1810. It was gradually realized that under southern conditions the crop yields a substantially larger amount of nutrients than turnips or swedes and the acreage has gradually

increased at the expense of the other roots. In northern England and in Scotland it is no more productive than swedes, but it is becoming increasingly common to find a small acreage of mangolds on northern farms, the object being to have a reliable supply of succulent food in late April and May, by which time swedes generally deteriorate in quality.

The mangold "root" consists of part of the stem immediately below the cotyledons and part of the true root tissue, enlarged and modified as a food reserve. Transverse sections show the concentric ring formation so well known in the garden beet. Like the turnip it is biennial, but by special methods it can be made to produce its seed within twelve months.

Fodder beet is the name given to a range of feeding roots derived either from sugar-beet alone or from crosses between sugar-beet and mangold. Incidentally, sugar-beet and mangold are closely related, being derived from the same wild species. The main differences between the two groups are in dry-matter content and in the growth form, especially the position of the mature "root" in relation to the soil surface. "Sugar-beets for Fodder," as the Danes call the types with the highest dry-matter content, closely resemble true sugar-beet, while the most widely grown varieties are intermediate, both in growth form and in dry-matter content, between the two parents.

Mangolds and fodder beet are capable of yielding more dry matter per acre than any other crop of a similar nature, and the greater part of the food material is in the form of sugar. The yield is highly elastic and can be influenced greatly by manuring. Indeed, where conditions are suitable and manuring is understood, crops of over 60 tons of mangolds and 35 of fodder beet, containing perhaps 6 tons of dry matter, have been grown.

The rôle of the mangold in the economy of the farm is similar to that of the turnip, but where climate and soil are favourable it is a better yielder. It is less liable to parasitic infestations, is a more certain cropper, and keeps better than any cruciferous root. The mangold is superior to the turnip as a food for dairy cows, since it does not taint the milk nor spoil the flavour of the butter. As a food for sheep, however, mangolds are not so satisfactory as turnips; although they can be safely fed to ewes after lambing, they tend to produce urinary disorders in male sheep and are unsuitable for tegs. In all cases, however, it is essential that mangolds should be properly ripened before they are offered to

stock, as immature roots cause the animals to scour badly. Because of their liability to injury by frost, mangolds have to be lifted before they are properly ripe. The lifting of the crop is therefore followed by a period of maturation in clamp, and farmers as a general rule do not feed mangolds to stock before Christmas. In most cases the leaves are left on the field and returned to the soil as manure, but in years of scarcity, after they have wilted, they can be used in limited quantities for feeding purposes.

Fodder beets have been grown in Britain, on any considerable scale, only since 1949; by 1953 the area had risen to 64,000 acres. Even on the Continent large-scale cultivation began only in the thirties.

In regard to production of total dry matter per acre there is little difference between fodder beet and mangolds, but fodder beet has a higher proportion of the total carbohydrates in the form of sugar. Fodder beet has the advantage in the lower total weight that has to be handled at harvest. Most important, perhaps, is the fact that pigs, whereas they cannot eat enough mangolds to provide a major part of their total energy requirements, can, in the later stages of growth and fattening, get up to half their total needs from fodder beet.

Varieties.—Mangolds (as distinct from fodder beets) may be classified according as their shape is long, intermediate tankard, or globe, and their colour red, orange, gold, or yellow, but except in the case of Golden Tankards, which as a group are uniformly high in dry matter and good-keeping but low-yielding, there is no relationship between the colour or form of the roots and their cropping powers or other economic qualities.

Mangold and fodder-beet varieties are best classified, from the point of view of utilization, according to their average dry-matter contents. It happens, too, that growth habit is correlated with dry-matter content, the high dry-matter fodder beets having the "root" mostly below ground-level, the mangold having it mostly above, and the intermediate types being about half-way between. The usual British classification is:—

	Dry-matter Content. Per Cent.
1. Fodder beet (high dry-matter)	18 to 22
2. ,, ,, (medium)	15 ,, 18
3. Mangold (high dry-matter)	11 ,, 15
4. ,, (low)	7 ,, 11

Typical examples of the first group are Hunsballe and Pajbjerg, and of the second Red Otofte and Pajbjerg Rex.

CULTIVATION

Soil and Climate.—The mangold is the typical root crop of all the heavy classes of land, but it grows best in a deep, rich loam and is unsatisfactory on shallow and very light soils. Since mangolds do best in sunny, dry climates, they occupy the greater part of the root-crop area in the southern and eastern counties. Once established they are highly resistant to drought; they do well where heat and drought would check the growth of cruciferous roots. It is in the south midland and south-western counties, however, that mangolds grow to perfection. In Scotland the climate is too dull and cold for the best results, and there is an increased tendency for the plants to bolt; but many farmers are now cultivating a small acreage for spring use.

Place in Rotation.—Mangolds have in the past occupied much the same place in the rotation as the turnip crop, because they facilitate the cleaning of the land in the same way. They cannot, indeed, be taken after a spring-consumed forage crop, as they have to be sown early; but they have a distinct advantage in that they can generally be grown continuously on the same land without their yield being diminished by disease. Since the carting of so bulky a crop over any considerable distance is a very laborious business there is a strong reason for restricting its cultivation to fields near to the point of consumption. On some clay-land dairy farms a "mangold garden" near the homestead is a more or less permanent institution. There is, however, the risk of infection of the land with sugar-beet eelworm. Mangolds, since they are rarely cleared till late autumn, and since the heavy carting damages the soil structure, must generally be followed by a spring-sown crop.

Preparation and Sowing.—The preparation for the crop depends on the soil texture, the preceding crop, the amount of couch or other root weeds, and, not least, the pressure of other work. Autumn ploughing should be the aim, but if farmyard manure is to be applied, later ploughing will generally be inevitable. In spring the "frost mould" should be kept on top—*i.e.* a second ploughing should generally be avoided. In the eastern and southern counties the treatment both for mangolds and fodder beet is the same as for sugar-beet (see p. 380). In the

north the crop is commonly grown on the ridge, and preparation is closely similar to that required for swedes (see p. 354).

The row width may vary from 20 to nearly 30 in., and there is an obvious advantage in making this the same as that adopted for the other main-root crop—whether sugar-beet or swedes, etc. The ultimate aim is a plant population of 20,000 to 25,000 per acre for mangolds and about 30,000 for fodder beet.

Mangold "seed," like that of sugar-beet, is, in fact, a fruit cluster containing two, three, or occasionally four true seeds. Seed-rates vary, according to the time of sowing and the state of tilth, from about 6 to above 15 lb. per acre. Too thick a plant makes for very laborious singling.

In the Midlands of England the usual time for mangold-sowing is from the second week to the end of April, but the crop may be put in up to the middle of May. In Scotland mangolds are sown about the beginning of May. If sown too early a proportion of the crop tends to bolt; if seeding is late part of the growing season is lost and the yield suffers. Fodder beet is sown at about the same date as sugar-beet and mangold.

Manuring.—Traditionally the most important and widely used manure for mangolds is dung. It has been found, however, that dung alone does not supply nitrogen fast enough for the best results, and a moderate dressing, supplemented by artificial fertilizers, will produce a greater yield than an excessive application of the natural manure. With regard to the mineral fertilizers, mangolds are less dependent upon phosphates than are turnips, but require a more liberal supply of potash. All roots of this family respond also to applications of common salt up to 5 cwt. per acre. It was formerly believed that the salt rendered available some of the soil reserves of potash and that the mangolds benefited indirectly, but it is now known that sodium can be utilized directly by the crop. Bearing this in mind, it is worthy of note that most of the crude forms of potash salts at present on the market contain a considerable proportion of common salt, and therefore have a particular value when applied to mangolds.

As regards the application of the fertilizers, some farmers apply the common and potash salts a considerable time before sowing is to take place, so as to prevent delayed germination or injury to the young seedlings; but this should only be necessary where exceptionally heavy dressings are employed. Ordinarily

the fertilizer should be applied immediately before sowing, but where no dung is used half of the nitrogenous fertilizer may be given as a side dressing at singling time.

The quantities of manure which can be profitably applied depend on the condition of the soil. On land of good depth and good texture the crop responds to heavy dressings more readily than on poorer or shallow soils. The optimal dressing of phosphate for mangolds, as for other crops, is generally highest in the north and west and least in the south and east.

The following is suggested as a suitable dressing under good conditions :—

15 tons of dung—ploughed in in autumn or applied in the ridges.

1 cwt. muriate of potash 1 to 4 cwt. of superphosphate 3 cwt. of sulphate of ammonia	distributed before seeding.

3 to 5 cwt. common salt.

After-cultivation.—The growth of mangolds being at the outset slower than that of turnips, horse-hoeing is generally necessary before thinning; this is difficult to perform unless the plants are growing on ridges. However, some farmers mix a few seeds of rape, mustard, or other quick-growing plant with those of the mangold in order to show the rows early. The rape or mustard plants are knocked out during singling. As a rule the crop is ready for thinning about four to six weeks after sowing; but in some districts a preliminary bunching is given, and the plants are afterwards carefully singled.

The tillage operations for the suppression of weeds are the same as for the turnip crop, and must be carried out until the leaves meet in the drills, care being taken to prevent any of the weeds from seeding, otherwise much of the cleaning effect of the crop is lost.

Towards the end of the growing period a proportion of the plants may " bolt," or produce their reproductive shoots. In some seasons the proportion is very small, but in others, especially in the northern districts, bolting is very troublesome. If this takes place, the shoots draw upon the reserves of food material in the roots and the yield is reduced. Bolting may be caused by a spell of cold weather at a particular point in the seedling's growth. Some strains, however, are much less prone to bolt than others.

Securing the Crop.—Mangolds grow well into autumn and it is desirable to give them as long as possible to mature; on the other hand they do not withstand much frost, so they have to be secured before this danger becomes serious. In practice, lifting and clamping usually take place towards the end of October or, in the south, before the end of November. Lifting is generally performed by two workers together, taking two rows apiece, and dropping the mangolds in the drill between them when they have cut off the tops. In this way four drills separate every row of topped mangolds, and this is ample room for taking through a cart when carrying takes place. If, however, the roots are not to be carted at once they should be collected into heaps containing about one-fifth of a load each and covered over with leaves, since, whereas growing mangolds are protected from frost by their tops, bare roots are much more easily destroyed. This practice is also believed to improve the keeping quality, as mangolds "sweat" a little immediately after pulling; if taken directly to the clamp, and especially if they have been pulled before their growth has ceased, they are apt to suffer serious loss through fermentation, heating, and decay.

It is important to avoid causing serious damage to the roots. They should not be tailed and, if storage is to be for a long period, it is better not to load them by a fork. Injuries are likely to give rise to bacterial decay and the destruction of a proportion of the crop.

Fodder beet, probably because of its higher dry-matter content, is less liable to frost injury than the mangold. The shallower-rooting types may sometimes be harvested in the same way as mangolds; the deeper rooting varieties generally have to be loosened by means of a beet "lifter." "Topping" of fodder beet may be merely the removal of the leaves or, alternatively, the removal of the crown as well. If the tops are to be fed the latter procedure is best, since the collection of leaves, without the crown, is laborious.

As a rule mangolds and fodder beet are stored in clamps in the vicinity of the feeding courts or sheds. In most cases the clamps are made as large as the roots can be conveniently heaped, because, once the first "sweat" is over, they can be kept in bulk without fear of further fermentation. Buildings that are well thatched can be filled almost to the roof, or clamps may be built against a wall, or between two parallel walls, to a great

depth. Nevertheless a good covering of straw is essential, as the outer roots are very easily frosted; and clamps in the open should get a final covering of soil.

Yield.—The average yield of mangolds is 19 or 20 tons, but crops of 30 tons are not uncommon, while 60 tons is occasionally reached with the low dry-matter types in particularly suitable areas such as South Devon. Yields of fodder beet vary with the variety as well as for other reasons. Fifteen tons is a good yield for the high dry-matter types.

Growing Mangolds for Seed.—Most mangold seed is grown in the southern districts, and the system employed enables the crop to be produced within twelve months. The seed is sown in a prepared bed about the beginning of August, superphosphate being generally used to promote strong root development. Transplanting can take place early in October. The land on which the plants are to be grown is dunged, ploughed, and given artificial manuring if that should be necessary; after harrowing it is marked off to allow each plant about 1 sq. yd. of ground. The plants (known as "stecklings") are then dibbled in. In winter the mangolds look rather backward, and severe weather may cause a few blanks that require to be filled from the seed-bed. In spring the crop can be given a top dressing of nitrate of soda. Early in the season the plants produce their reproductive shoots, and, when a fair height has been attained, the tips may be cut off to encourage the lower branches to spread. When the first fruits begin to harden and turn brown the crop should be cut with a hook, tied into bundles, and stooked to dry. When dry, the crop can be stacked or threshed. The yield varies from 10 to over 20 cwt. of seed per acre. The seed of sugar-beet can be produced in the same way. Recent experiments with sugar-beet for seed suggest that a suitable manuring is about 10 tons of dung, with 2 cwt. superphosphate, 1 cwt. muriate of potash and 3 cwt. common salt at planting time, and 2 cwt. of any nitrogen fertilizer in spring.

Diseases of Mangolds.—Mangolds and fodder beet are liable to attack by the same diseases and pests as sugar-beet (see pp. 388-389).

CARROTS

Our cultivated carrots have been obtained from the wild carrot, which is a common annual or biennial weed, by a process of selection which has fixed a biennial habit and a fleshy root. There

are numerous varieties, varying from the small, sweet garden sorts to the large, white-fleshed field carrots which are grown exclusively for stock. The feeding value is substantially higher than that of swedes or mangolds. The yellow varieties are very rich in carotene, which is the precursor of vitamin A.

Carrots grow well under all our climatic conditions, but large-scale cultivation is almost restricted to two soil types—very deep, sandy loams and the light peats of the fen-lands No attempt should be made to grow field varieties on shallow or stony land, as the crop is certain to be inferior and unprofitable. Crops grown on heavy land are very difficult and costly to harvest.

It is important that deep cultivation should be given in preparing land for carrots, and if there is even the slightest pan it must be broken up by subsoiling. When the deep working has been completed a fine surface tilth should be prepared as for the turnip crop, and the ground must be thoroughly cleaned. The importance of clean land for carrots can hardly be overestimated, as the seedlings are so slow-growing and delicate that they cannot compete with weeds. In recent years, however, the culture of the crop has been revolutionized by the introduction of selective oil sprays for weed control. Special oil fractions or even (with suitable precautions) tractor vaporising oil can be used at an early stage of growth (see p. 157). Pre-emergence sprays may also be used (see p. 156).

The seed may be obtained either in its natural state or with its bristles machined off. In the former case it is difficult to sow as the appendages cause the seeds to cling together, and before being put through the seed-drill it should be mixed with a large bulk of sand or dry soil. About 4 lb. of seed is sufficient to sow an acre, if the plants are to be singled. But many commercial growers now sow at a rate of ¾ to 1 lb., and dispense with singling, which is a very laborious operation. Row widths vary according to district and other circumstances. Seven to 10 in. is sufficient, with relatively wide spacing in the rows, but mechanical cultivation is difficult. A row width of 14 to 18 in. facilitates tractor work. But if the land is free from perennial weeds, and if a selective weed-killer is used to deal with annuals, little inter-row cultivation is required. Another plan is to have narrow and wide rows alternately—about 8 and 16 in. respectively. This plan has the advantage that the double rows can be lifted by means of

an elevator type of potato digger. The seed must not be placed too deep (1 in. is sufficient) or the plants will fail to come to the surface. The crop may be singled to intervals of 4 to 5 in., but because the chief demand is for a small-sized carrot, large areas are now sown thinly and not singled at all.

Some growers treat the crop, so far as fertilizers are concerned, in much the same way as sugar-beet. But on land that is in reasonably fertile condition the crop gives little response either to phosphate or nitrogen. Potash, however, will usually produce a response. If dung is used it should be ploughed in deeply in autumn; but it is better to grow carrots in the second year after applying farm manure. Unrotted dung tends to make the carrots fork and reduces their value. For land in poor condition a suitable manuring would be 10 tons of dung ploughed in early in autumn, 3 cwt. of superphosphate and 1 cwt. of sulphate of potash in the seed-bed, and 1½ cwt. of nitrate of soda put on as two top-dressings, at intervals, after the plants have established themselves.

Maincrop carrots are sown in April or early May. In the mildest districts crops for the early market may be sown in February.

The subsequent cultivations consist of keeping the land thoroughly clean by spraying, tractor-hoeing, and hand-weeding. The last is very laborious, and every effort should be made to eliminate it. Motorized hoe equipment (see p. 183) is very suitable. In large-scale production singling is rarely done.

Although carrots can stand a certain amount of frost, it is usual to lift and store in October or November those intended for the winter and early spring market. The lifting is usually done by two workers, one loosening the soil with a fork while the other draws out the roots and twists or cuts off the leaves. The carrots are stored in small clamps built after the fashion of potato pits, and provided with a ventilating shaft of straw to prevent overheating. Some growers, especially in milder areas, take the risk of leaving the crop in the ground, and lift as required for market.

The average yield of mature carrots per acre is about 11 tons. On suitable soils 20-ton crops are not uncommon, and yields of 30 tons have been recorded.

The chief pest of the carrot is the larva of the carrot fly. There are two generations each year and most of the first generation emerge in the latter part of May. They shelter in such places as

hedge bottoms and, after mating, lay their eggs in the soil very near to their hosts, which may be attacked any time after the cotyledon stage. The maggots burrow into the roots, so destroying many plants and doing much damage to others. When fully fed the larvæ pupate and produce a second generation of flies during August to October. These in turn give rise to more maggots which tunnel in the root tissues and do great destruction even after the carrots have been lifted and stored. On a garden scale, creosote-soaked cord or light rope stretched between the rows of carrots, or repeated applications of naphthalene, will deter the flies from laying in the vicinity and so give a measure of protection. On a field scale, reduction in the damage may be brought about by spraying a suitable insecticide along the hedgerows and margins of the fields to destroy the flies before they have deposited their eggs. One material that gave good results was a solution in water of molasses and sodium fluoride, but this was so readily washed off by rain that repeated applications were required. A preparation of D.D.T. is much more convenient because it is far longer lasting.

KOHLRABI

In the kohlrabi that part of the primary stem above the cotyledons thickens and develops into a turnip-like food store. This " bulb " grows entirely above ground, and as it thickens the lower leaves fall away, leaving characteristic broad scars. There are two main classes of varieties, the one being entirely green and the other purplish.

Kohlrabi takes the place of a root crop in the economy of the farm, and can be safely fed to all classes of stock. As a food for cattle it is excellent, being less liable to cause scouring than turnips or swedes. It has a particular value for dairy cows in that it does not taint the milk as do turnips. When fed to sheep it is usually eaten off, and it is more economical than swedes, as only the little thin roots are left in the ground. Large quantities are fed to pigs, and as its nutritive value is much higher than that of the mangold, it has been found that sows having the run of a little grassland can be kept on kohlrabi without the addition of concentrates between the weaning of one litter and the approach of farrowing. Kohlrabi is used for culinary purposes and is generally prepared like a dish of turnips.

The crop is grown chiefly in Essex, Suffolk, and Kent, mostly on the stiffer class of land. Its requirements are more akin to those of the mangold than to those of the turnip. For this reason kohlrabi is often grown in southern districts where turnips form an uncertain crop.

In growing kohlrabi the land is prepared as for turnips, and sowing takes place in April. The seed is sown on the flat at the rate of 4 lb. to the acre, and the drills are 18 to 24 in. apart. When the plants are sufficiently forward they are singled to intervals of 10 to 12 in. Sometimes the plants are started in a bed and dibbled in by hand in May or June; and because they can be transplanted very successfully, a small bed may be sown in March and the plants used to fill the gaps in mangold crops.

In the manuring of the crop it is usual to apply a moderate dressing of dung supplemented by artificials, but the plants do not respond to nitrogenous dressings as well as mangolds or cabbages. A suitable manuring would be 12 tons farmyard manure, 4 cwt. superphosphate, 3 cwt. kainit, and 1½ cwt. sulphate of ammonia in two dressings.

It is usual to feed the crop in the autumn, but if necessary the bulbs can be stored in clamps like turnips. If a hardy variety is selected, however, the plants may be allowed to stand out until well into the winter and lifted as they are required.

Other Root Crops.—Considerable acreages of red-beet and of parsnips are now grown, in rotation with corn and other ordinary farm crops, in certain areas. For information about these the reader is referred to the Bulletin on *Root Vegetables*, of the Department of Agriculture, or to standard works such as Hoare's *Vegetable Production for Market*.

CHAPTER V

SUGAR-BEET

SUGAR-BEET is a biennial plant closely related to the mangold and red-beet. It differs from the mangold in that its parsnip-shaped "root" develops in the ground and only the crown, bearing the leaves, appears above the soil. Sugar-beets are white-coloured; their average weight is about 1 lb.; they do not "bleed" like mangolds and garden beet when cut; they have a high dry-matter content, their sugar-content alone amounting to from 13 to more than 20 per cent. of their weight. A typical analysis is:—

Sugar	16·50 per cent.
Fibre	4·70 ,,
Albuminoids	0·60 ,,
Other organic matter	1·05 ,,
Ash	0·75 ,,
Total dry matter	23·60 ,,

The sugar-beet of to-day has been developed from an early type of mangold by breeding and selection, which have been carried out with the primary object of obtaining a maximum yield of sugar per acre. The early work of improvement took place in France and Germany, but beet cultivation has now extended to every country in Europe, to America, and to many other temperate countries throughout the world. Although the main object of growing beet is the production of sugar, the by-products—tops and pulp—are important to many growers, especially dairy farmers. In other cases the tops are ploughed in as manure.

Beet tops, whose food value is rather better than that of swedes, can be consumed on the ground by sheep or carted for cattle. On light peaty land it has become a practice to run cattle over the beet fields after harvest, with straw and water as the only supplements. Heavy soils would, in many cases, be damaged by treading, and on light mineral soils there would be a risk that the cattle would ingest harmful amounts of sand. Beet tops have the disadvantage that when fresh they tend to cause violent scouring. This trouble is usually avoided by allowing the

leaves to wilt for ten to fourteen days, but if this is not sufficiently effective it may be desirable to feed along with them 0·1 to 0·2 per cent. of ground chalk. Another fault is that when tops are fed in too large quantity to milch cows they may produce a fishy taint in the milk. Forty pounds per head per day should be the maximum.

Beet pulp, which is the residue of the roots after the sugar has been extracted, is a very valuable substitute for the ordinary root crops. In the wet state it is of rather poorer feeding value than white turnips, but it is nevertheless the only succulent food given to many continental herds during winter. The dry pulp is sometimes used to absorb molasses, which is another by-product of the factory. In this form it has, like the tops, a tendency to produce a taint in milk. The wet pulp, having a high and variable moisture content, is costly of transportation, and it is therefore used mostly by farmers in the vicinity of the factories; it can be stored in pit silos, either with or without the addition of the tops and leaves, for long periods. Most factories also produce dry pulp in which the moisture-content is reduced from about 93 to 11 per cent. The dried pulp is, of course, much less bulky, and it can be sent long distances at relatively small cost; it can be stored in bags for an indefinite period. Since 1951 increasing quantities of dried pulp have been processed into solid blocks, which are more convenient and less wasteful than the bagged loose product. When used in moderate quantity, 1 lb. of dried pulp may replace 7 lb. of swedes or mangolds, or 10 lb. of soft turnips. It is comparable in energy value with oats, but much lower in protein. The dry material is generally swelled by soaking it in water before feeding, but soaking is unnecessary provided the animals have access to water.

The Extraction of Sugar from Beet.—For the extraction of beet-sugar, factories are erected in districts which are likely to be suitable for the cultivation of beet in quantity. The crop is grown for the factories at a contract price per ton of washed beet containing a standard percentage of sugar, and a bonus is given where the sugar-content is above this standard or a corresponding deduction is made for a short-fall. The work of extraction commences towards the end of September and the last beets are usually disposed of by the middle of January; for the remainder of the year the factories are idle and employ only a maintenance staff. There are seventeen factories in England and one in

Scotland, all under the control of the British Sugar Beet Corporation, which promotes and carries on research on the crop and which has a field staff.

The beet is consigned to the factory as it is required, and on its arrival a representative sample is taken in order to estimate the " tare " and the sugar-content. The " tare " is the difference in weight between the beets as delivered in a more or less dirty condition and the same beets after washing and, if necessary, dressing; " top-tare " and " dirt-tare " together ordinarily amount to some 14 to 16 per cent. of the gross weight. The sugar-content is estimated in the factory laboratory: it generally increases up to the end of October, about which time the crop also reaches its maximum and thereafter decreases. As the farmer gets nothing for the tare on his consignment but has to pay carriage thereon, it is obviously in his interest to deliver the roots in as clean a condition as possible, and properly topped.

In the manufacturing process the beets are first washed and after weighing they pass to the slicing machines, which reduce them to fragments suitable for extraction. The sliced beet then has its sugar extracted by passing it slowly, step by step, up a long sloping cylinder down which hot water is run. Thus the beet slices are first extracted by juice, then, as the sugar is removed, by a solution of decreasing concentration and finally by hot water. The residual pulp is removed and sold, either wet or after desiccation, for stock feeding. The purification of the juice from the extractor is brought about by the addition of lime and the subsequent precipitation of the lime with carbon dioxide. The juice is next evaporated to a syrup and, after further purification, it is concentrated in vacuum pans by boiling at a sufficiently low temperature to prevent caramelization. When the crystals are sufficiently formed, the material is centrifuged to remove the non-crystallizable matter, which is the by-product known as molasses or treacle. Beet-factory waste lime or sludge can be bought at an almost nominal price. It contains nearly 50 per cent. of water and only traces of phosphate and other plant nutrients. It is widely used as a source of lime for application to farm land in areas adjoining the factories.

Quality and Varieties.—Beet roots should average 1 lb. or a little more in weight, richer soils producing the larger size; the shape should be that of a nicely formed cone without any

tendency to forking or fangy growth. There should be no coarseness about the crowns, very little of which should appear above the ground. A well-developed leaf system is essential for a good crop, but an over-development due to excessive nitrogenous fertilizer is often correlated with lateness, poor root development, and reduced sugar-content.

A high sugar-content is desirable and this is usually more easily obtained by growing a large number of medium-sized roots on a given area than by having larger and wider spaced plants. The sugar-content, however, must be considered in conjunction with the yield. There are three types of sugar-beet available to the grower, namely, "E" strains which produce a high yield but contain a relatively low proportion of sugar, " N " strains that are medium in yield and sugar-content, and " Z " strains that give a relatively low yield but contain a high proportion of sugar. Varieties should be selected from the lists approved by the factories according to the type that is likely to be most profitable under local conditions. A high sugar-content is most desirable from the factory owner's point of view, but a big yield with a relatively low sugar-content may be more profitable to the grower. At one time the Z strains were recommended for wet districts, but since most of the British crop is grown under fairly dry conditions, in practice the E and N types are now used almost exclusively. Where the crop is to be lifted before the roots are fully developed, N types are to be preferred.

Bolters in crops of sugar-beet are very common, and if they occur early in the season they are extremely undesirable, as their roots become woody and of little value for sugar extraction. While the proportion of bolters is undoubtedly influenced by the occurrence of a cold spell when the plants are in the three- or four-leaf stage, and also perhaps by the manuring, bolting is an hereditary characteristic which is more common in certain varieties than in others. The incidence of bolting may be reduced by delaying the date of sowing, but recent experiments have shown conclusively that early sowing makes for higher yields. This is particularly marked in seasons when the crop suffers an attack of virus yellows (see p. 388). Moreover, plant breeders have recently produced a number of " bolt-resistant " strains, which can safely be sown as early as mid-March. Kleinwanzleben AA is a notable example, which, however, is outyielded by others if sown at the normal time, *i.e.* April.

As regards the general question of the choice of variety, trials of fourteen strains carried out in 1948-51 gave the following results:—

For mineral soils the following were satisfactory, and the first three particularly good. The order given is that of yield of sugar per acre:

Klein E (German seed).	Goldsmith's Dobrovice.
Hilleshog.	Webb's No. 2.
Klein E (Sharpe's).	Garton's C.
Cannell's No. 22.	Cannell's No. 937.

For black fen soils the most suitable types were Hilleshog, Klein E (Sharpe's), Klein E (German seed), and Bush E.

BEET CULTIVATION

Soil and Climate.—The best soil for beet is a deep free-working loam, but the crop has been grown quite satisfactorily on well-drained soils of practically all types. Light soils have the advantage of being warm in spring and thus enabling the young plants to establish themselves more quickly; they also allow of the crop being lifted in a somewhat cleaner condition, and they do not suffer much damage by puddling during a wet harvest season. On the other hand, clay is unsatisfactory because of the difficulty of poaching when driving off the crop. Stony soils are unsatisfactory because they cause the roots to fork, and soils that possess a pan are quite unsuitable for growing beet until the pan has been broken up by deep ploughing or sub-soiling. Beet cannot be grown profitably on land that requires liming, and it is important to have the lime requirement of the soil estimated before trying to grow the crop. With regard to quality, it is found that the highest sugar-content is obtained when the beet is grown on light land and the lowest on peaty soil.

Sugar-beet has been tried in most parts of the country. In the colder and wetter districts of the north and west it has not been a very satisfactory crop, for while it has done well in a few favoured places, the yield has too often been too small to be remunerative. On the other hand, many areas in the east, south, west Midlands, and especially in East Anglia, are suitable for the cultivation of beet on a large scale. The cultivation of the crop is likely to be profitable only on soils in a fair state of fertility. Owing to the infrequency of hard autumn frosts in Britain, the roots—which

withstand 8° of frost when lifted, and more in the ground—do not require elaborate storage precautions; but it is necessary that the roots be protected in really hard weather. Roots left in small heaps in the field, and those on the top and sides of clamps, can be so damaged by frost that sugar extraction at the factory is slowed down and made more difficult. They may also decay after thawing. Field heaps should be covered with a layer of tops, and clamps should be strawed when hard frost threatens.

Place in Rotation.—In this country beet generally takes the same place in the rotation as the root or potato crop, *i.e.* between two straw crops, where maximum benefit is obtained from the opportunity of cleaning the land. However, if land is really foul, beet should be avoided, as the cost of hoeing and singling is apt to be prohibitive—unless, perhaps, where the crop is sown in very wide rows. Beet has at times been grown successfully on the same ground for several consecutive years, but in the long run the practice leads to the infestation of the soil with beet eelworm. As such an infestation is a very serious matter, successive beet crops should be avoided. British factories now make it a condition of their contracts that beet shall be grown at intervals of not less than three years, and the *Sugar Beet Eelworm Order*, 1952, imposes cropping restrictions in certain specified areas.

Preparation and Sowing.—In early districts it may be possible to clean the stubbles after harvest, and this should be done whenever it is practicable. In autumn or early winter the dung is driven out and spread in the usual way, and these operations are followed by ploughing. The ploughing should be as deep as the nature of the soil will permit, and in some cases it may be profitably accompanied by subsoiling; it should be done early so that the furrow-slices get the benefit of long exposure to winter frosts. Most authorities are against cross-ploughing in spring, maintaining that this practice turns down the frost mould and tends to dry the soil, thus hindering the preparation of a fine tilth and involving the risk of an unsatisfactory "plant." In spring, harrows should be sufficient to prepare a fine surface mould, and cultivators or grubbers can be employed to break up the furrow-slices to their full depth so as to allow of easy penetration of the roots. A full germination of the seed depends on an adequate moisture supply, and this is best secured by consolidating the surface soil with rollers both before and after sowing.

The yield of the crop depends very largely on the number of beets that can be grown to the acre, and experience has shown that on average land an endeavour should be made to produce at least 30,000 plants on this area; on very rich soils, where individual roots grow large, fewer plants will give the same yield, but on very light soils even more plants are required. Loss of plants due to weather conditions, pests, and accidents in hoeing are usually considerable, and actual plant populations in Britain (apart from partial failure in establishment) are commonly between 20,000 and 24,000. The higher plant densities usually give the higher sugar-contents. One plant to 220 sq. in. will give about the required number per acre, but in order to allow for the inevitable blanks it is better to plan the spacing at the rate of one to 200 sq. in. An ideal apportionment of soil and light would be secured by placing the beets 14 in. apart in 14 in. rows, but this would not permit of horse or tractor cultivation, and would make for difficulty in lifting. In practice the allocation of 200 sq. in. per plant has therefore to be secured by sowing in rows 18, 20, or 22 in. apart and singling to intervals of 11, 10, or 9 in. respectively. As good beets require to be at least 10 in. apart it is obvious that with wider rows than 20 in. it will be impossible to get the full number of plants per acre. On the other hand, wider drilling facilitates summer cultivation, saves seed, and reduces the labour of singling and lifting, and there may be occasions when these advantages compensate for a slightly smaller crop.

Sugar-beet is usually drilled on the flat. This method has, of course, advantages with regard to the conservation of moisture in a dry climate, and it allows of the rows being placed closer together than is practicable with a system of ridges. Notwithstanding the advantages of cultivation on the flat, many farmers in the north prefer to grow their beet on ridges. Ridging greatly simplifies the subsequent cultivations and enables weeds to be kept in check from the outset. The crowns of beets growing on ridges need not necessarily become exposed if they are well earthed up.

The amount of untreated seed that is recommended for sowing beet is from 15 to 20 lb. per acre, the heavier seeding being necessary when sowing is early and the tilth is not very good. In theory this is considerably more than should be required; but as the subsequent yield of the crop depends so much on a full and uniform plant, and since there are so many risks of mortality after

sowing, it is found in practice that light seeding is very false economy. It is only fair to point out, however, that where there is a combination of first-class tilth and good weather conditions a heavy seeding may produce so thick a stand that singling is slow and costly. The seed should be sown at a depth not greater than 1 in. Beet and mangold seed are sometimes treated with strong sulphuric acid to break down the corky mass in which the seed is enclosed and so to give a quicker and more uniform germination, but the operation is not one to attempt on the farm. Mechanical milling of the seed also improves germination. These treatments, of course, make the seed smaller, and the rate of sowing has to be adjusted according to the number of germinating seeds per pound. Another milling process produces "sheared" or "segmented" seed clusters of which quite a high proportion contain only a single germ. The use of this type of seed, especially if it is sown by a spacing drill, facilitates singling; but results, on the whole, have not been satisfactory from the point of view of regularity of stand. Decorticated or "rubbed" seed is now widely used. A further step is to surround each segment with clay, bitumen-bonded ash, or other material, the resulting pellets being made of uniform size. Pelleted seed can be much more accurately spaced than the small and light rubbed material. The process of pelleting is now being applied, in the United States, to a considerable number of seeds, including carrots and other vegetables.

The "rubbed" seed now in use is generally graded for size. The grade $\frac{7}{64}$ to $\frac{11}{64}$ in. consists very largely of singles, but cannot be used alone owing to loss of seedling vigour. Seed-rates can safely be reduced when rubbed seed is used. In fact, the advantage in its use is lost if a normal seed-rate is employed. The object is, of course, to produce a thin and uniform stand, with a minimum of "doubles."

In the south-east, sowing ordinarily begins in the latter half of March and in a normal season is completed in April. In the north-east of England and in Scotland the usual starting dates are early and mid-April respectively. It is better to be a little early than a little late, for, while sowing may be extended into the early part of May, it would appear that every day lost after the optimum sowing time for the district results in a smaller yield. With most varieties there is a period in the life of the young plants when they are so susceptible to a set-back that cold weather

—not necessarily frost—may cause them to bolt later in the season, and the actual date of sowing is therefore determined to a large extent by the risk of cold spells after the seed has germinated. The susceptible period lasts for about a week or a fortnight, and when it has been passed, later spells of cold weather will not cause bolting. It is consequently quite possible for late-sown beet to be so influenced by cold that it runs to seed, while an early-sown crop, which has passed the susceptible stage, remains unaffected. This effect of cold is an example of *vernalization*, *i.e.* a change in plant behaviour induced by exposure to an abnormal temperature. It has been shown that when germinating beet seed is exposed to a particular temperature, under controlled conditions, all the plants will bolt.

In the past, the Smythe type of drill has been generally used. Recently introduced "precision" drills (see p. 189) were giving promising results at the time of writing. It is possible to use a corn drill if the unwanted coulters are put out of action. Unless there is a special press on the drill, rolling should be carried out after sowing.

Manuring.—As has been previously pointed out, the first essential in the preparation of the land for sugar-beet is to ensure that the soil contains an adequate supply of lime, for optimum growth does not occur unless the reaction of the soil is *p*H 6 or over, and failure may occur between *p*H 5 and 5·5. The most valuable manure is dung, which, if applied at the rate of 10 tons and upwards per acre, along with artificials, will produce a considerably larger crop than can be obtained by the use of artificials alone. Heavier dressings of farmyard manure do not give a corresponding increase of beet, and are liable to delay ripening and depress the sugar-content of the crop. The dung should be applied in autumn or early winter, and even if the system of cultivation permits, dunging should not be done in the ridges. Green manures may be used for beet but they are not so effective as farm manure.

With regard to phosphatic fertilizers, superphosphate is most commonly employed, about 3 cwt. per acre being applied in conjunction with dung, or 2 cwt. more where the crop is being grown with artificials only. As a rule the optimal dressing is higher in the north and west than in the south-east.

Potash is essential for sugar-beet, yet on soils that have plenty of body and contain considerable potash reserves it may be

unnecessary to apply potash manures in addition to farmyard manure and common salt. At the other extreme are sandy and peaty soils which are very poor in potash, and when beet is grown on land of this type it responds to dressings of up to 4 cwt. of kainit (equivalent to about 1 cwt. of muriate of potash) per acre in conjunction with dung, or twice this amount when no farm manure is employed. While kainit or potash salts are recommended for sandy soils, muriate of potash is generally used on heavier soils.

Common salt, applied at the rate of 5 cwt. per acre, gives almost or fully as good results as potash salts, and on light land 2 to 4 cwt. per acre is recommended even where potash is also employed. If nitrate of soda is applied as the source of nitrogen the dressing of salt may be proportionately reduced. It should, however, be remembered that sodium salts—either as common salt or in kainit—may cause injury to the texture of heavy soils. As is true also of mangolds, it is usual to obtain a marked response from common salt even when the potash supply is optimum. In other words sodium, as such, acts as a plant nutrient in the case of beet and mangolds.

The nitrogen fertilizer which is generally preferred for beet is nitrate of soda; but where sulphate of ammonia is cheaper it is quite satisfactory if common salt is used in conjunction. The optimal amount of sulphate of ammonia is from 3 to 4 cwt. per acre, both for crops that have been dunged and those that are being grown without farmyard manure. Dressings of this order may slightly depress the sugar-content, but more than compensate for this by increasing the tonnage. No more than 4 cwt. should be applied, even on light land.

The fertilizers are applied at seed-time, and there seems to be no advantage, at least in the drier regions where most of the beet crop is grown, in reserving part of the nitrogen for a subsequent top-dressing. Care should be taken to avoid the excessive use of nitrogen fertilizers on land that is in a high state of fertility, otherwise the ripening of the crop will be delayed and the quality injured.

It is clear from the above that no standard manuring can be prescribed for sugar-beet, because so much depends on the nature of the soil and its previous treatment. Where no precise local information is available, growers usually obtain quite satisfactory crops by employing the manuring which they have found to be

satisfactory for mangolds, with perhaps 50 per cent. more nitrogen.

The fertilizer should be thoroughly worked into the top 3 or 4 in. of soil during the process of seed-bed preparation. If these operations include a very shallow ploughing, the fertilizer may be applied in advance of this. It appears that there is nothing to be gained by "combine" drilling or fertilizer "placement." Indeed, combine-drilled fertilizer impedes germination. The use of a placement drill, putting the fertilizer in bands on either side of the seed (2 in. to the side and 1 in. deeper), saves an operation, but as said does not give higher efficiency than broadcasting and working into the seed-bed.

Subsequent Cultivation.—In from ten to twenty days after sowing, according to the weather conditions, the sugar-beet plants should be through the ground and the land may be given its first horse-hoeing. As soon as the beets reach the four-leaf stage, and when they are still very small, they should be singled. Early singling is of the utmost importance, because if the plants are allowed to grow unsingled until they become drawn and spindly—especially if weeds are also present—they will not yield satisfactorily; indeed up to a ton of beet per acre can be lost for every week's delay. In order to thin the plants the hoe should be at least 1 to 2 in. narrower than the proposed spacing—say an 8 in. hoe for 10 in. intervals—and the work must be done with very great care in order to ensure that the best plants are left, that there are no blanks, and that the ground is thoroughly cleared of weeds. In many countries beet is thinned and the soil is consolidated about the roots of the selected plants by hand. Hand-work is more thorough than can be accomplished with an ordinary hoe, and is probably worth while when the crop is being grown on suitable land, which will give a good return for intensive management, and where cheap labour is available. A good method is to use a short-handled hoe in the right hand and to separate the plants with the left. Sometimes bunching is performed as a preliminary to singling, and it has the advantage that it enables the "cock beet," which it is desirable to select, to assert itself. Many farmers pay their workers a bonus according to the regularity of the spacing which they achieve in singling. Singling is an expensive operation, since if a man is to make good work he can generally do no more than a quarter or a fifth of an acre per day. After the plants have recovered from singling, the crop is again

horse- or tractor-hoed. This is followed by hand-hoeing between the plants and the removal of any doubles that have been left inadvertently at singling. Yet another power-hoeing should be possible before there is danger of damaging the leaves. More after-cultivation may be given, but if the work is overdone and the roots are damaged, the yield will suffer.

"Chopping out" or "bunching" may be achieved by cross-blocking by mechanical hoes, used at right angles to the line of the drills. It can also be done by "down-the-row" thinners, a number of which were under trial or in course of development at the time of writing. Both techniques achieve a considerable saving of labour and give good results where the original "plant" is full and even. Experimental electronic thinning machines were also showing some promise.

A four-row horse-hoe or a still wider tractor implement is generally used for inter-row cultivation. These are generally fitted with discs which can be used for the early operations in order to ensure that the young plants are not covered with soil and smothered.

In all probability a number of bolters will have to be dealt with during the growing season; in very unfavourable seasons 5 to 10 per cent. of the crop runs to seed. In rare cases where the plants have had a check during the susceptible stage a greater number may bolt. Beets that bolt early in the season become so poor in sugar and so woody that they should not be sent to the factory, for there is a risk of their being included in the sample which is taken for analysis; but those which bolt about the end of summer are little inferior to the ordinary roots and are quite fit for delivery. When cutting off the tops at harvest the early bolters can be distinguished by their woodiness.

Harvesting.—When beets are ripe the outer leaves tend to fall down and the whole of the foliage assumes a shrunken appearance. As the factories require beet from about the end of September, lifting commences at this time, although the beet is not fully ripe and has not developed its maximum sugar-content. At the end of October the beet is at about its best, but the consignments despatched to the factories at the end of the year may have undergone some shrinkage. In order to give growers equal advantages in time of delivery, and to keep the factory fully employed throughout the three-months' season, dated loading permits are allotted to each grower.

Beet cannot be pulled easily by hand as can turnips and mangolds because it is far too deep-rooted. Small areas can be dug with a special two-pronged beet fork, but whenever a commercial acreage is being grown the crop should be harvested with the aid of a special lifting plough. In one type of plough there are two lifting prongs with digging points so placed that they enter the ground on either side of the row of beets, and as the implement moves forward the roots are caught on either side and wedged upwards clear of the soil. The other common type has one digging share which loosens the beets on one side and passes them upwards so that they are easily withdrawn. A considerable number of mechanical harvesters are now available (see pp. 229-231), and in 1953 over a fourth of the total acreage of the crop was lifted by machine.

In hand-lifting, after the plants have been loosened by the beet plough, they are drawn up and knocked together to remove as much as possible of the adhering soil; they are then laid in rows for topping. Topping consists of cutting the beet through at the level of the lowest leaf scar. As previously pointed out, the whole of the top should be removed, because if part is sent to the factory its food value is lost and it will be counted as part of the tare on the consignment.

It is best to harvest the last of the beets in November and to place in clamps that portion of the crop which has to be delivered at a later date. Protection from frost is generally considered to be unnecessary, but some covering is desirable if a spell of severe cold seems imminent. If beet is left in the ground as late as December the land is likely to be very wet and the harvesting operations to be more difficult and costly. Where topping is done as a separate operation, lifting must follow within a day or two, since the sugar-content of the roots, left buried in the soil, falls rapidly.

Yield.—On light land that is not in a very high state of fertility 9 tons of washed beet per acre is considered a fair yield and 11 tons would be exceptionally good. On naturally good land that is also in high condition and capable of yielding up to 25 tons of mangolds, 12 to 14 tons of washed beet per acre can be got. On the very best soils 15 tons per acre is sometimes exceeded. The national average yield has been rising markedly in recent years, and in 1953 reached 11 tons per acre. The sugar in British-grown beets generally runs from 16 to 18 per cent. of the weight

of washed roots. The weight of the crowns and tops varies greatly, but a 10-ton crop of sugar-beet will yield about 8 tons of crowns and leaves.

BEET DISEASES AND PESTS

Beet is attacked by a number of the fungoid diseases and insect pests that also affect mangolds, but their incidence is seldom serious unless the crop is grown for several years on the same land. Sometimes, however, a disease known as black leg, which is caused by one or other of several fungi, causes considerable loss in the seedling stage, and it is believed that dressing the seed with mercurial dust is an effective means of prevention. A further advantage of treating the seed with sulphuric acid is that fungoid spores are destroyed.

Wireworms can be very damaging to young seedlings. If the soil population is known to be high the seed should be treated with a suitable dust containing benzene hexachloride. In extreme cases the soil itself should be so treated. Damage may also be minimized by early and thick seeding, firm seed-beds, and by manuring to promote rapid growth in the early stages.

Heart-rot may develop in beet (and mangolds) when the plants are suffering from boron deficiency, a condition which appears to be most frequent on soils of high humus-content that have recently been limed. An application of about 12 to 20 lb. of borax per acre has been found to prevent the condition developing and also to cure it in its early stages; but it is important to know that large dressings of borax are likely to be toxic. Another deficiency which sometimes occurs is that of manganese, and it is the cause of "speckled yellows."

Virus yellows is the most important disease of sugar-beet with which we have to contend; it has been known to reduce the sugar yield by 40 per cent. The symptoms are a very marked yellowing of the under-part of the leaf blades, only the larger veins retaining their green colour. The disease is not transmitted through the seed but is carried by aphids—*e.g.* the common peach aphis and the "black fly"—from infected beet and mangold crops to the healthy plants, over-wintering taking place in seed crops, in mangold clamps, and on escape plants of beet or mangolds. Some degree of control of the disease may be effected by growing the seed stecklings in isolation so that vectors cannot carry the virus from them to the commercial root-crops, by

spraying to destroy the aphids, or by producing disease-resistant varieties.

The beet eelworm has caused immense damage in areas of continental Europe where beet has been grown too frequently on particular fields. The pest has appeared in England, and although it is not yet widespread it is obviously important to keep it under control. As already mentioned, the only insurance is to avoid successive beet crops on particular fields.

There is a Bulletin of the Department of Agriculture on *Pests and Diseases of the Sugar-beet.*

CHAPTER VI

PULSE CROPS AND FLAX

BEANS

THE common bean (*Vicia faba*) is one of the most ancient of cultivated plants. Although field beans are grown in most parts of Britain it is in the eastern and midland counties of England that they are cultivated to the greatest extent. The bean acreage in this country decreased greatly in the fifty years up till 1939, largely because the crop is suited to the very heaviest land, much of which, during the period in question, was put down to permanent grass; there was, however, a considerable revival during the war, stimulated largely by the shortage of imported feeding stuffs. As beans constitute the only highly nitrogenous concentrated food that can be grown in a great many localities, they are of great value for blending with starchy cereal grains in preparing well-balanced rations for stock, especially dairy cows. Cracked beans may be fed to horses, calves, and sheep, but bean meal is the most useful form for pigs, fattening cattle, and dairy cows. Where, as in the north, beans are cut while still somewhat succulent, the straw is nutritious, and when chaffed and mixed with other foods is a valuable addition to the rough fodder of the farm. Beans form an important constituent of many soiling and ensilage mixtures, and produce a very large bulk per acre when thickly sown and heavily manured.

Beans, however, have a number of disadvantages. In hot seasons the crop may be very severely attacked about the beginning of July by the black aphis, and although winter beans are less susceptible than the spring varieties they also are attacked in very bad years. When the whole crop is covered with aphids its yield is likely to be negligible, and it may be most profitable to make it into silage. Rooks are another common cause of serious damage. Wind frosts may injure the plants in March or April and blacken them to the ground, and beans that are sown early and become " proud " in autumn may be affected in the same way. May frosts, even if relatively slight, are also very harmful. Frosted crops never recover properly and they leave bare patches of ground

which tend to become foul with weeds. A badly damaged crop had better be ploughed in, though if the damage is slight it may be worth while to drill in a few bushels of peas or spring cereal in order to fill up the blanks. The most serious disease is Chocolate Spot, which affects winter beans and is caused by a common grey mould fungus (*Botrytis*) that becomes parasitic in some seasons. The attack takes place between April and July, the symptoms being reddish-brown discoloration of the leaves and stems and blighting of the plants. Frost damage and soil deficiencies may predispose the crop to attack, but there is no cure for affected plants. Spring beans are seldom, if ever, attacked. Beans cannot be grown on the same ground year after year, since they are liable to a disease akin to clover sickness. On the whole, a crop of beans allows the land to become rather dirty, and if drilling is carried out in rows wide enough apart to permit of horse-hoeing, a maximum yield cannot be expected. Moreover, in certain years even widely spaced crops are impossible to clean. In some areas mixed crops of beans and cereals (see p. 394) are preferred to pure crops, and there is some evidence that the mixture yields more than the two constituents grown separately. Moreover, the protein-content of the oats seems to be improved when they are grown in association with a legume.

Varieties.—The two main types of beans which are generally recognised are the winter and spring varieties. Winter beans, which will grow under relatively poor soil conditions, are sown in autumn and withstand fairly severe frost; they develop strong lateral branches, produce the largest yields of pulse and straw, and come to maturity much sooner than the spring sorts. Spring varieties resemble winter beans in appearance but are less hardy and do not tiller or crop so well; they are very late in ripening, and if not sown early may fail entirely in a dry year. As is the case with wheat, the winter crop, because of its greater productiveness, is invariably preferred where it will stand the climate; but the climate of Scotland and the north of England is too severe for winter beans. If spring beans are grown, the earlier the seeding the greater and more certain the crop, provided that late frosts do no damage. The Carse, the Scotch Horse, and the Scotch Tick are examples of spring-sown varieties grown in northern localities. In the English bean-growing districts many of the strains are known merely as spring beans or winter beans; but the Tick is a spring sort cultivated to a considerable extent. Tick beans are

smaller, rounder, and smoother than the common winter and spring sorts. The Heligoland is an early, small, dark-grained variety and the Mazagan is a large flat-sided sort. Some of the commercial stocks consist of mixtures of types, and since most varieties are largely cross-fertilized in the field—to the extent of about 30 per cent. in the case of winter types—the maintenance of purity of types is difficult.

At the time of writing, active work on the selection and breeding of winter beans had been proceeding for several years. More than a hundred strains had been examined by the National Institute of Agricultural Botany, and it had been shown that the various stocks showed fairly marked differences in economic characters—disease resistance, vigour, etc.; but critical trials on a national scale had not been carried out.

THE CULTIVATION OF BEANS

Soil and Climate.—Beans are grown to a greater or less extent in most of the arable districts of Britain, but they give much the best results when grown on stiff clay soils, and may even fail on the lighter portions of a field. Probably the very best soils are the chalky boulder clays, as the bean does best where there is plenty of lime; but the crop will not thrive unless the land be well drained. On land rich in humus the yield of grain is often disappointing, though the weight of straw may be very great. When once established on good soil the bean resists drought well, but because of its liability to suffer from frost, the winter varieties are reliable only in the south. The risk of loss in winter is greatest on very wet soils.

Place in Rotation.—Beans may take the place of clover in a rotation, as, being legumes, they tend to increase the soil reserves of nitrogen. They may be grown between two cereal crops, but, as has been said, cannot be regarded as a satisfactory cleaning crop. In many clay-land rotations beans are grown between two crops of wheat, and no particular trouble is taken to suppress the weeds that creep in; but such rotations usually contain a bare fallow, and, moreover, a dense crop of wheat has an excellent smothering effect, so that this practice does not make the land as foul as might be expected. The bean is one of the best crops to grow on broken-up grassland, as not only does it crop well on such a soil but it is probably more resistant to

wireworm and "leather-jacket" attacks than any other farm crop—flax and linseed only excepted.

Preparation and Sowing.—Winter beans should be sown early, and most farmers like to get the operation over before the end of the second week of October. On rich land, September-sown beans may develop too strongly before the cold weather sets in and consequently suffer from frost. On the other hand, sowing after the first of November is very risky, and it is better to wait and put in a spring variety. The usual autumn seeding is at the rate of 2½ to 3 bushels (of 63 to 66 lb.) per acre, but field experiments have shown that higher rates (3½ to 4 bushels) commonly give better results. Spring beans must be sown early, and once the beginning of February is reached the sooner the seed is in the ground the better. It is not always possible to get on the land as early as this, but at any rate the beans should be sown before any other spring crop, and a seeding of at least 3½ bushels per acre is necessary. If beans are too thickly sown, or grown in close rows, there is a tendency for the foliage to develop strongly at the expense of the grain yield; indeed, light must be able to reach the lower flowers if the pods are to set. Some farmers prefer new beans for seed; others sow year-old seed. It matters little which is used; the choice should be those that have been harvested in the better condition and show the higher germination. As with many other crops, the methods of preparation and of sowing depend on how the farmyard manure is applied, and, of course, whether autumn sowing is to be adopted. Seeding may be carried out in any of the following ways:—

1. Land for spring beans may be deeply ploughed in autumn and left exposed to the weather throughout winter. In early spring the soil is cultivated and harrowed, and drawn up into 26 in. ridges by means of a double-mould-board plough. Farmyard manure is spread in the bottoms of the drills, and the seed is broadcast, or a special three-row bean drill is employed to drop the seed on the top of the manure. The ridges are then split to cover the seed, and harrowed and rolled before the plants come through the ground. Beans grown in this way may be looked upon as a true fallow crop, as the method permits of the thorough cultivation of the soil between the rows. But the suppression of weeds is never so successful as in the case of potatoes, because the smothering power of the crop is much less. This system is common in Berwickshire and Northumberland.

2. In the west of Scotland beans are often broadcast at the rate of about $2\frac{1}{2}$ bushels per acre on the ploughed grassland in February and harrowed in. About three weeks later a late variety of oats is sown at the rate of 2 to 3 bushels per acre on the same land and harrowed in also. The name "mashlum" is given to this mixed crop; the object of sowing the two species at different dates is to secure that the different plants will be ready for cutting at the same time. After threshing, the beans may be separated from the oats by screening or the mixture may be ground for stock food.

3. Beans may be sown on the flat in rows about 20 in. apart by means of a grain-drill fitted with special spouts. This may be done either in autumn or in spring. The operations preceding drilling consist of ploughing, cultivating, and harrowing until a moderately fine tilth has been secured. This method will produce a large crop, but as inter-row cultivation can be carried out only during the early stages of growth the land tends to become rather foul. It is the standard practice in the midland and eastern counties.

4. Beans were at one time dibbled by hand. Long-handled dibbles were used, and the beans planted in every second or third furrow-slice on freshly ploughed land, the land being afterwards harrowed. The advantage of dibbling was that on wet soils the seed could be sown earlier than by any other means, but under modern conditions the labour cost is too high.

5. One of the cheapest and best methods of sowing is to plough beans in. Under ordinary circumstances a row is ploughed in under every second furrow, though every third furrow may be preferred where tractor cultivations are likely to be required, the furrows being about 10 in. broad but not more than about 4 in. deep. This is done by attaching a small drill or hopper to every second or third plough, or to one of the bodies of a two-furrow tractor plough, the seeds being deposited in the open furrow and covered over by the next furrow-slice. Seed put in in this way is left at a uniform depth and protected from the ravages of birds.

Manuring.—Traditional practice is to apply about 10 tons of dung, without artificials, in cases where beans follow a cereal, and to give neither dung nor fertilizer where they follow a long ley. Nitrogen fertilizers are, of course, not used in practice, and in some experiments they have depressed the yield of pulse, a result that may be due to over-development of leafage in the early stages of growth. On all except potash-rich soils a dressing

of the muriate, from 1 to 2 cwt. according to conditions, is to be recommended.

Beans respond less markedly to phosphate, but if the phosphate status of the soil is low a dressing of 2 to 3 cwt. of superphosphate, or the equivalent amount of basic slag, should be applied.

There is some advantage to be gained, where the necessary equipment is available, in the placement of fertilizer. The fertilizer bands should be 2 in. away from the seed and 1 in. below it.

After-cultivation.—As soon as the land is sufficiently dry in March the beans should be harrowed. This tears out numbers of annual weeds and breaks up the caked surface of the soil so that the air gets access to the plant roots and growth is stimulated. When further drying has taken place, horse- or tractor-hoeing may be commenced and should be continued throughout the season as often as is practicable. The type of hoe employed will depend on the width between the drills. By far the most thorough cleaning can be carried out when the rows are far enough apart to admit of the use of single-row cultivator. However, a three-row horse-hoe or a row-crop tractor with suitable equipment will do good work in narrow drills before the plants become too tall. If the land does tend to become foul when the crop is ripening, a thorough scarifying of the stubble after harvest will do much to minimize the ill that has been wrought. When horse-hoeing is no longer possible, hand-hoeing should be carried out if labour can be spared. Winter beans, unless the growth is very lush, may with care be safely sprayed with Dinoseb It is true that beans are more susceptible to damage than are peas and that with late-sown spring beans the risk is too great to be taken. In any case the precise stage of growth is important, and success requires specialist knowledge and experience.

Harvesting.—Winter beans are generally ready to cut about the beginning of August, but the spring varieties are very late and are seldom ripe until after the cereal cutting is over. The time of cutting has a very great influence on the feeding value of the straw; when cut in green condition bean straw is very little inferior to good hay, but if allowed to become dead ripe it is not only unpalatable but fibrous and innutritious. Moreover late cutting gives rise to considerable loss through the beans "shelling" during harvest. If the crop is taken a little early, the only inconvenience will be a slight delay until it is dry enough

to stack. The best way to judge the ripeness is to examine the scar (hilum) on the end of the bean where it is attached to the pod. Individual seeds may be considered ripe when the hilum has turned black; but the pods ripen over a considerable period, the lower ones first. If cutting is delayed until the uppermost pods are ripe the lower are very liable to shell during the cutting and subsequent handling. The usual compromise is to cut when the middle pods are ripe. Earlier cutting, though it may avoid loss by shelling, results in a large proportion of shrivelled seeds.

Cutting is most expeditiously carried out by means of a binder, but where the crop is short and there is a large number of pods near the ground the use of a reaper may result in a smaller proportion of loss, and very occasionally, when the lowest pods are touching the ground, the crop is pulled by hand. After cutting, the sheaves are stooked in the usual way and stacked when they are dry. No crop while in the stook will withstand bad weather better than beans. They may be left in the field until the more susceptible white crops have been secured, and suffer no damage if they get a brisk shower while being carried; indeed a shower will help to prevent the pods splitting open and so save loss during forking and carting. Because of the large number of pods exposed on the outside of a bean stack, many farmers carry the thatch right down to the ground in order to provide better protection.

New beans do not form a healthful food for stock and the crop is better left unused until January; moreover they may be too soft to grind. In practically all cases the bean crop is the last on the farm to be threshed, and in some cases the pulse is not fed until it is a year old.

Yield.—The bushel weight of beans is 63 to 66 lb., and the average yield is commonly put at 4 qr., or 18 cwt. per acre; but it appears that, by contrast with other crops, yields have been tending to fall; the national average for the years 1942-1951 was estimated at only 15·1 cwt. The average proportions of pulse and straw are 40 and 60 per cent. respectively, *i.e.* an ordinary crop will produce nearly 1½ tons of roughage.

PEAS

Peas are very similar in composition to beans, *i.e.* they contain nearly 20 per cent. of digestible protein and have a low fibre-content. They are therefore valuable for blending with cereals

in the making up of balanced rations for live stock. When intended for animal food, peas may be grown either pure or in mixture with oats, and the mixed crop may be either treated as a grain crop or cut green for soiling, ensilage, or hay. Where the mixture is intended to be ripened and harvested by binder the proportion of peas must be kept low—say one part of peas to four or five parts of oats—otherwise the crop may become so tangled as to create great difficulties in harvesting. A mixture with a higher proportion of peas may be treated like " threshed dried " peas, *i.e.* be cut with a pea harvester, a cutter-swather, or a mower, and cured in the swath.

Dried peas for animal feeding (as compared with garden varieties) are more dwarf in habit and mostly have coloured flowers. Varieties in this group are the Maple (mottled in colour), the Dun or Partridge, the Common Grey, and the Prussian Blue. The Maple is the most important, followed by Dun. Marathon Maple is a late, high-yielding type, while Minerva is a recent product of the Cambridge Plant Breeding Station. The white- and bluish-skinned varieties may be used either as human food or for animal feeding, whereas Maples are rarely saleable for the former purpose. On the other hand Maples are the favoured food for racing and other pigeons, and find a limited market, at what is often a profitable price, for this purpose. Harrison's Glory, Dutch Blue, and other varieties formerly grown only for human consumption (" threshed dried peas ") yield well, and were at the time of writing being increasingly grown for stock-feeding.

Peas grown for human food are dealt with in four different ways. Firstly, any of the dwarf garden sorts, excepting the most delicate, can be grown in the field and be picked for market when the pods are still green and the seeds still soft. In many cases it is unprofitable to make more than one picking, and where this plan is followed the plants are pulled up and stripped. Secondly, the crop may be mown and the whole material sent to a factory, either to be canned or to be preserved by " quick freezing." Shelling is done mechanically by a " viner " and the shelled peas are then graded according to size and tinned. The haulm, which is much more nutritious than that of a ripe crop, may be brought back to the farm and may be either fed to stock at once or be ensiled. Naturally, canning peas are normally grown on contract, and the canning factory ordinarily supplies seed of the variety

stipulated. The varieties used are "garden" ones and include Thomas Laxton, Onward, Lincoln, Kelvedon Wonder, Miracle, and Gregory's Surprise.

Thirdly, the crop may be ripened and threshed, when either of the above-mentioned types may be grown. The threshed dried peas may be cleaned, sorted, and put up in packets for sale, or alternatively they may be processed in order to soften them and then canned. Either large-seeded varieties of the Marrowfat type, such as Harrison's Glory or the Dutch Marrowfats, or small round-seeded sorts like the Lincoln Blue and Prussian Blue, are suitable for this purpose, the former under high-fertility conditions and the latter on poorer land. The Dutch "large blues" —Servo, Rondo, and Unica—are also grown, but are rated less highly for processing. They are, however, very short-strawed, have a shorter flowering season, and often yield better than the Marrowfats.

In general, varieties that produce long straw are suitable for field cultivation only on poor soils, and very dwarf sorts should be chosen for the richest soils, such as silts and fens.

For green picking, *i.e.* for direct sale on the vegetable market, it is usual to grow a succession of varieties and also to "stagger" the dates of sowing. In the drier areas and on light free-draining land the first sowings may be made as early as December or even November, despite the fact that, even in the milder areas, the resulting crop may be winter-killed in occasional years. Further sowings are made at intervals till May or June. Popular varieties for autumn sowing are Meteor and British Lion.

Bulk sowings for canning or the production of dried peas for human food, and also of field peas for stock feeding, are generally made in the latter half of March if conditions are suitable, but an earlier opportunity, any time after mid-February, should not be missed. Seed sown under wet conditions in cold soil is very liable to rot, but seed dressings containing TMTD give good protection.

The best all-round pea soil is a medium calcareous loam, but dry sandy or gravelly land is required for the production of early picking crops. Maincrop sorts sown in March do quite well on fairly heavy land provided it is well drained.

As regards manuring, farmyard manure and other rich organic materials tend to produce rank growth, even on the poorer soils, and are therefore seldom used, but little critical evidence on the

point was available at the time of writing. Experiments have shown that the crop responds most markedly to potash, and to phosphate only when the soil shows a marked deficiency. It has been common practice to apply small amounts of nitrogen, but experiments have failed to show that a profitable response is regularly or often obtained on naturally rich soils. Where the preceding crop has been generously fertilized it is unnecessary to apply any fertilizer. In other circumstances a suitable application might be 1 cwt. each of superphosphate and muriate of potash, or the equivalent in the form of a special pea fertilizer (containing 10 per cent. phosphate and 20 per cent. potash, with no nitrogen).

Most growers of green picking peas have been accustomed to apply some nitrogen, since this is thought to improve the colour of the pods and to bring the crop a little earlier.

Fertilizers should either be worked deeply (3 to 4 in.) into the seed-bed or preferably be sown with a placement machine. The bands should be 2 in. away from the row of seed, and a little below the seed level. The normal dressing of fertilizer (2½ cwt. per acre of the compound mentioned above) will give an extra 2 cwt. of peas if the fertilizer is applied as above rather than broadcast.

Considerable differences are to be seen in the matter of the distance between the rows. The seed can be sown with an ordinary grain drill, *i.e.* with about 7 in. between the coulters. This method, of course, precludes inter-row cultivation, and is only to be recommended in cases where it seems that weed control can be secured merely by harrowing in the early stage of growth or where it is proposed to control weeds by selective herbicides. Peas will stand harrowing well, but many experienced growers prefer to grow in drills sufficiently wide apart (about 18 in.) to permit of tractor-hoeing. A wide range of annual weeds may be controlled by the careful use of Dinoseb (see p. 160). MCPA has sometimes been used with success, but in other cases there has been considerable damage to the crop.

The seed rate varies from 1½ to 2½ cwt., depending mainly on the size of seed. The seed-bed should be fine and rather firm, a result that is best obtained by autumn ploughing and by cultivating and harrowing. Inoculation of the seed (with nodule-forming organisms) is only rarely necessary, but treatment of the seed with TMTD preparations is worth while

in the case of winter sowings in order to minimize the risk of rotting.

The land is generally rolled about the time or soon after the seedlings emerge, and if many annuals appear within the following week or two the land may have one or two light harrowings. Thereafter, inter-row cultivation, with horse- or tractor-hoes, should be repeated as frequently as may be necessary until the plants begin to sprawl across the rows.

As already indicated, the harvesting of peas is a peculiar problem because the plants are not only more or less prostrate and entangled but are attached to each other by their tendrils. Moreover the crop must be dealt with before it is fully ripe, since the lower pods will begin to shell while the tops are still green. It should not be left beyond the stage when the lower two-thirds or three-quarters of the plant has turned brown.

As already said, picking peas are generally uprooted and stripped of their pods by hand, the haulm being left on the ground until it is fully dried out and then collected.

Until comparatively recent times canning or processing peas have ordinarily been cut by mower, with "pea lifters" attached to some of the cutter-bar fingers and sometimes with a further special fitment known as a swath mover, *e.g.* the swinging windrower (see p. 197). More recently the Leverton cutter (see p. 203) has proved useful on stone-free land, but the most satisfactory equipment is the still newer "cutter-swather." This machine is useful over a considerable range of crops, including lucerne.

In any case, the cut crop, after some preliminary wilting, is put up in large cocks or, better still, on to tripods, the number required being ordinarily twelve to sixteen per acre. The crop can safely remain on tripods for many weeks and still yield a sound and bright sample.

When drying is completed the material from the cocks or tripods is carted and stacked, the handling being as gentle as is practicable. Alternatively, the crop may be left in windrows to dry and then be "combined," the machine being fitted with its pick-up attachment.

From what has been said it will be understood that the cultivation of peas on a commercial scale is restricted to the drier parts of the country. A wet harvest is apt to result in serious difficulty.

FLAX AND LINSEED

Flax and Linseed are distinctly different cultivated strains derived from the same original species (*Linum usitatissimum*). Cultivation began very early and flaxen fabrics occur among early prehistoric remains in Egypt. The plant is an annual with slender erect stems and usually blue flowers; some white-flowered varieties of flax, however, occur. The seed is produced in globular fruits or bolls. Flax, having been developed with the object of producing long straight fibre, is taller than linseed—up to 40 in.—and when well grown has few and short branches. It gives a low yield of seed—normally only 3 or 4 cwt. per acre—even when allowed to ripen fully. Linseed is shorter and more widely branching in habit, so that its fibre is of poor quality. The yield of seed from improved varieties, under good growing conditions, may be expected to reach 10 to 12 cwt. per acre, and yields of 20 cwt. have been recorded.

The ripe seed has an oil-content of the order of 35 per cent. and about 20 per cent. of digestible protein. Ground linseed is the most nutritious of all common concentrates, with a starch equivalent of about 120. It is laxative and healthful and is useful as a constituent of calf meals and as a conditioner for convalescent animals of all sorts. The ground seed, when soaked in cold water, sometimes develops poisonous qualities, due to a glucoside; it should therefore either be fed dry or else boiled or scalded.

The great bulk of linseed that is grown is used for the extraction of oil, the residue being the universally esteemed linseed cake. The oil is a "drying" one, *i.e.* when exposed to the air it oxidises into a dry, elastic, durable film. Previous boiling increases the drying quality. Linseed oil is widely used in the manufacture of oil paints, linoleum, and waterproof materials—*e.g.* "oilskins." Raw linseed oil is in general use as a mild purgative for farm stock, and small quantities may be given to animals that are out of condition or are being prepared for showing. Linseed and its products have a marked tendency to soften the body fat of animals to which they are fed. This is no particular disadvantage in the case of sheep and cattle, but oily fat is very objectionable in a bacon carcass.

Flax fibre is the material from which linen is made, but it is also used for cordage and fire hose and a variety of other purposes. The fibre is the bast tissue which extends throughout the whole

length of the stem; it is very durable and strong. The process of extraction starts with retting, *i.e.* soaking in water. Most retting is now done in artificially heated water, the process being completed in a very much shorter time than was involved in the old process of soaking in pond water. When retting has gone so far that the bast separates readily from the woody tissue, the material is dried, artificial drying being now the rule. The brittle, woody core of the stem is then broken by means of rollers, and the material is finally scutched to remove the broken pieces from the long silky fibre.

Both flax and linseed grow on a wide range of soils, but on heavy land it is difficult to obtain the necessary fineness of tilth, and very thin, dry soils are unsuitable, more particularly for the fibre types. The crop has little competitive power, so that the land should be clean. Weeds are particularly objectionable in flax, and any large proportion may result in rejection of the crop by the factory. Redshank (*Polygonum aviculare*) is particularly objectionable. The use of weed killers on flax requires special care (see p. 165) but is possible. Where flax is grown and is to be pulled by machine special care must be taken to level the ridges and fill the open furrows before sowing otherwise the machine cannot operate satisfactorily.

Neither type of plant is a "gross feeder," and as a general guide it may be said that the appropriate level of soil fertility is about the same as for the stiffer-strawed sorts of barley. Linseed can have rather more nitrogen than flax. The crop is generally grown after corn but on the poorer sorts of land it does well after a ley.

The plant is practically immune from wireworm attack and is disliked by rabbits. It is attacked by "leather-jackets" and by the linseed flea-beetle. It makes a good nurse crop for grass and clover seeds. In preparing the soil the initial ploughing should be fairly deep, but it must be done early if the very firm and fine seed-bed, which is necessary for successful establishment, is to be obtained. In spring, rolling and harrowing must be repeated until a "turnip tilth" has been produced.

The seed should be sown at a depth of ½ in. It may be broadcast and covered by a light harrowing, or it may be drilled. The American alfalfa-drill (see p. 188) is very suitable. Failing this an ordinary grain-drill, with coulters 6 or 7 in. apart, may be employed, though drilling in two directions is desirable in order

to get proper distribution over the ground. Some drills, however, may not be adjustable to the half seed rate—*viz.* about 40 lb. per acre—that is then required. Rolling is desirable to get proper consolidation, but if the soil is liable to "cap" or "crust" the roll should be followed by a light harrow.

The seed rate for flax is relatively high (90 to 112 lb.) since a close stand is desirable to prevent branching; 70 to 80 lb. is usual for linseed. Very early sowing involves the risk of frost damage, but it is a mistaken idea that good crops can be obtained by seeding in May or June. The crop indeed has a short period of growth, but late sowing often results in a severe check by drought. In England late March or the first week of April is probably the optimum time, and in Scotland the second or third week in April. Late sowing, in certain years, results in heavy damage by flea-beetle.

If any considerable number of tall-growing weeds appear in a flax crop they must be hand-pulled or spudded. Flax must be pulled (not reaped) in order to obtain the full length of fibre. Pulling machines (see p. 203) are reasonably efficient in the hands of experienced workers. Flax must be harvested before it is ripe in the ordinary sense. In general the finest quality of fibre is obtained by pulling at the stage when only the base of the stem has begun to change colour. At this stage the yield of seed is small and much of the seed is immature.

The optimum time for cutting linseed is more difficult to determine, since the bolls ripen, in succession, over a period of several weeks, and the earlier begin to rupture and shed their seeds before the last are filled. Harvesting should commence as soon as the earliest pods are dry and brittle.

Flax is bound in small sheaves which are set up in stooks for a few days or a week. If rain threatens, the sheaves should be built in small cocks, preferably round tripods. In favourable seasons the material may be carted and stacked from the stook. Every endeavour should be made, during handling, to keep the straw straight and undamaged.

Linseed is harvested in the same way as a cereal, but it is more difficult to cut. The bottom of the stem is extremely wiry, and it is well not to attempt to make too close a stubble. The binder knife must be carefully sharpened at short intervals. Sometimes there is a good deal of trouble in adjusting the divider. Threshing may be done with the ordinary type of machine if suitably adapted

(see pp. 210-211). Combining is possible, but a special fitting is necessary to crack the bolls, which may otherwise fail to release their seed.

Breeding of flax has been carried out in Northern Ireland and recently at the Flax Research Unit in Norfolk, and the varieties there produced are the best suited to British conditions.

At one time commercial Argentine seed (Plate Linseed) was commonly grown, but it has been shown that newer Canadian varieties are much more productive. The Canadian variety Royal is popular among late-maturing types, but may be replaced by the Swedish Valuta, which is a heavier cropper. For northern and other late districts Dakota may well replace the Canadian Redwing.

RAPESEED AND COLESEED

Following the development of rape as an oil seed in Scandinavia during the war years came a significant increase in the British acreage of this crop.

Cultivation is broadly similar to that of mustard and other brassicas grown for seed.

There are both winter and spring types of both species, swede or true rape and turnip rape. The spring varieties, though the less productive, are more popular than the winter sorts, which must be sown in August. The respective yields may be about 8 to 10 cwt. in the one case and 16 to 18 cwt. in the other. Sowing of the spring crops can be left till late in May, and can therefore leave time for a partial fallow. Matador and Rapido are good varieties of the winter swede and winter turnip groups respectively. Regina is the best known of the spring swede group, and Nida is the most popular of the spring turnip type. Others are Gute, Black Argentine, and Sweet German.

The cultivation of rape as a forage crop is described at page 421.

CHAPTER VII

FORAGE CROPS AND SOILAGE

VETCHES

VETCHES or tares (*Vicia sativa*) are leguminous plants which are very widely cultivated for forage purposes. A proportion must necessarily be ripened for seed, but practically all the produce so obtained is used for sowing purposes, the grain very rarely being fed, like beans and peas, to stock. Tares may be grown alone or in mixture with other plants such as beans, oats, or rye; they may be soiled, made into silage or hay, or folded with sheep or pigs. The nitrogenous nature of the vetch makes it extremely valuable for feeding to stock, and its proper use obviates the necessity of purchasing expensive cakes and meals; but while it can be fed to all classes of stock with safety it should not be supplied in excessive quantities when in a wet or succulent condition, as it is then very liable to cause bloat.

There are two common varieties, namely winter and spring tares, which differ little in appearance; and another sort known as the Gore which produces bigger seed and more bulky foliage. The winter vetch is hardy, and may be sown in autumn in the midland and southern counties, but it cannot always withstand the more severe winter climate of the north. Very often both winter and spring sorts are sown, and the dates of seeding so arranged as to produce a supply of green fodder throughout a large part of the summer. When the crop is cut early for hay or soiling, a certain amount of aftermath develops which is useful for grazing sheep or other stock, and winter tares may be cut in time to allow the farmer to sow a crop of turnips or plant cabbages on the same land. Spring vetches may be removed in plenty of time to allow of the preparation of the land for wheat, and the crop is sometimes grown for ploughing under as a green manure.

Tares form a useful crop on all classes of land, but attain their greatest perfection on clay soils which are rich in lime. Their rich fibrous roots do much to improve the fertility and

texture of poor, heavy land. For soiling purposes vetches may be grown throughout the full range of our climatic conditions, but no attempt should be made to grow seed or to make the herbage into hay except in early districts of low rainfall. Even in favourable localities ripening and drying are difficult to secure and the seed crop seldom gives complete satisfaction except in dry years.

Vetches may follow a white crop in the rotation, and although their habit of growth makes it impossible to suppress weeds by hoeing they produce an excellent smothering effect, and if cut green, leave the land cleaner than either beans or peas. In Scotland small acreages of tares are often grown to supplement the pastures in the fall of the year, and pieces of land which are not cleared until late in spring—*e.g.* land on which potato pits have been situated—are frequently used for this purpose.

Winter vetches are usually sown in September and October. The seed may be broadcast at the rate of $2\frac{1}{4}$ cwt. (4 bushels) per acre on the ploughed land and harrowed in, or drilled at the rate of $1\frac{3}{4}$ cwt. (3 bushels) per acre with an ordinary corn-drill on a bed that has been prepared by cultivating and harrowing. It is even possible, by drilling on stubbles which have been broken by cultivators, to avoid the cost of ploughing, but this is satisfactory only on particularly clean land. Spring tares may be sown in February, March, and April, and although later sowings may be carried out there is a risk of the plants being adversely affected by drought, and in all cases of late sowing a heavier seeding is necessary. Frequently, however, vetches are not sown alone but are grown along with other species. Owing to the great difficulty of securing seed crops in good condition some farmers sow about $\frac{1}{4}$ bushel per acre along with beans. These give the tares plenty of support, and the troubles associated with the lodging, moulding, and decay of heavy tare crops are altogether avoided. When threshing has been completed the seed of the two species may be separated by screening. A good mixed crop, whether for silage, for green fodder, or for ripening, may be got by sowing 1 bushel of winter beans, $\frac{3}{4}$ bushel of winter vetches, and $1\frac{1}{2}$ bushels of winter oats per acre; but the most suitable proportions are determined by local soil and climatic conditions.

Although vetches are sometimes given light dressings of dung they respond best to phosphates, and potash is necessary on light soil only. A dressing of 4 cwt. of high-grade slag, or an equivalent quantity of ground mineral phosphate, is all that is needed on

heavy land. This should be applied with the seed. On light soil 2 cwt. of steamed bone flour and ¾ cwt. of sulphate or muriate of potash will probably be more satisfactory. Superphosphate may be used on all soils that contain plenty of lime.

Winter tares grown either alone or with a cereal may be harrowed and rolled in spring, rolling being more important on soils that puff up under the influence of frost.

The time of cutting vetches will depend on the purpose for which the crop is grown. If the tares are intended for silage, cutting should take place when the lower pods are nicely filled but still soft. If required for hay, cutting should be delayed until the plants are a little more mature, because there is a loss of moisture in the ripening process, and up to a certain point this can be more safely effected when the crop is growing than when it is on the ground. If for seed, cutting should take place when the pods are filled and have lost their juiciness and the colour of the foliage is changing to brown. When the crop is a mixed one and the vetches are supported by beans or a cereal, cutting may be performed with an ordinary mower. Cutting is most troublesome when the vetches are grown alone and ripened for seed, as they frequently form a tangled mass which is badly laid, and although a mower may do the work when the fingers of its cutter-bar are fitted with pea lifters, it is frequently necessary to cut the heaviest portions with a scythe. When intended for soiling or ensilage, the green crop is often allowed to wilt for a few hours so that it may lose a proportion of its moisture before being carted. When hay or seed is required, the vetches are put in small heaps and treated in the same manner as a crop of peas. As tares are difficult to secure in perfectly dry condition and tend to become mouldy in the stack, it is often worth while to build small stacks round tripods, which permit of a free circulation of air, an elevated situation where there is plenty of wind being chosen. Thatching should be done early as the herbage is very porous and does not run off the wet. The seed is separated by an ordinary thresher and the straw forms an excellent feeding roughage.

A moderately good crop of tares will yield 10 tons of green forage per acre. Green tares weigh well, but the moisture-content is high, frequently 80 per cent. The bushel weight of the seed is about 64 lb., and a yield of 24 bushels (14 cwt.) is not often exceeded; the yield of threshed straw varies from 20 to 25 cwt. per acre.

LUCERNE

Lucerne (known in America as alfalfa) is a very valuable leguminous forage plant which is grown largely on the continent of Europe and also in North and South America, South Africa, Australia, and New Zealand. As a pure crop it is almost wholly restricted to the south-eastern half of England, but it is being increasingly used over a wider area, in mixture with grasses, to provide both hay and grazing (see p. 462). Its roots penetrate suitable soils to great depths, rendering it extremely resistant to drought, and tapping sources of food which are seldom reached by other farm plants. The plant is a true perennial, and when properly manured will continue to produce heavy crops year after year; but it cannot compete with weeds, and when grown on dirty land its productiveness gradually falls off until it has to be ploughed up. Mixtures with grasses are much less liable to weed infestation than pure crops. If, however, the land be properly prepared and the crop well managed, even pure stands will last for six or seven years, and in this time, through the agency of the bacteria in its roots, the crop influences the nitrogen reserves in the soil in such a way that the benefit can still be observed after several years of arable cropping.

Lucerne is often cut green and used for soiling purposes. Three or four cuts may be be made in a single season, yielding a total of up to 15 tons of forage per acre. The crop is kept most productive if, on the one hand, the stems are cut before they become too mature, and on the other hand, the plants are not cut so close to the ground that their reserves are exhausted. In practice this may be secured by cutting before flowering, when a satisfactory but limited bulk has developed, and by leaving a rather long stubble; but there must be a long enough interval between the last two cuts of the season to enable the plants to build up reserves for wintering. The herbage is best fed in a wilted condition and can be given to all classes of stock; pigs that are kept in confinement are fond of it and benefit by it greatly. Pure stands of lucerne may be grazed, but under certain conditions that are not fully understood the herbage is apt to cause bloat in cattle and sheep; moreover, close grazing by sheep, or treading by heavy cattle when the land is soft, is liable to damage the crowns, which are above or very near to the soil surface. Severe treading may occasion a serious loss of plants, and consequent weed invasion. In admixture with grasses

the tougher and more dense sward is much more resistant to damage by treading. It is a common practice to graze the second growth of lucerne after an early crop of hay and, naturally, there is no objection to grazing in the last year of a lucerne ley.

Lucerne may be cut twice in the season for hay or green fodder, and in the warmer areas even three times. The crop may be made into hay or silage, yielding up to 3 or 4 tons of dry matter, with a high protein-content—18 or even over 20 per cent. Like other leguminous plants it requires careful handling, for the leaves become brittle while the stem is still succulent. Lucerne-grass mixtures are more easily converted into good silage than is pure lucerne, but the latter can be made into satisfactory silage by the addition of molasses (see p. 505), or without such addition if the green material is allowed to wilt to a moisture-content of about 65 per cent. It is being cultivated in this country for the production of lucerne meal. For this purpose the crop is cut when in a young condition, artificially dried, and afterwards ground. The dried product, if produced rapidly from herbage that has not been allowed to wilt, retains most of the carotene-content and vitamins of the fresh plant. It also has a very high protein-content and is very rich in calcium. Lucerne meal may be used as a substitute for green food for any class of stock.

Lucerne thrives best on a deep, calcareous loam overlying a pervious subsoil, because under these conditions it can obtain the complete freedom from acidity which is so necessary for its healthy growth, and for the nitrogen-fixing bacteria. It grows, however, on practically all soils, including clays, that are neutral or alkaline in reaction and properly drained, and it is only on sour land, or where the water-table rises high in wet periods, that its cultivation should not be attempted. The warm and somewhat dry southern counties are most suitable, as many of the common varieties have difficulty in withstanding the cold climate of the north and the heavy rainfall of the west. Another factor adverse to the growth of the crop is the absence from many British soils of the strain of nodule-forming bacteria which normally inhabits lucerne roots; but provided the soil is not acid, this can be remedied by inoculation. An immense number of lucerne varieties are known, and seed is often named according to its country of origin. Those which produce satisfactory results in Britain may be classified as follows:—

1. *Flammande*, *e.g.* Du Puits, W. 268, Chartrain Villiers,

Sochville. These originate in French Flanders and are characterized by earliness, great vigour of growth, and high yields, especially when mown rather than grazed.

2. *Provence*.—These types are moderately early and seem to thrive under a wide range of climatic conditions. A recently introduced strain, Marais, was showing promise at the time of writing.

3. *Grimm* types are late and, having a characteristic semi-prostrate growth habit, were favoured for incorporation in grazing mixtures. There is, however, no convincing evidence that they are better for this purpose than the foregoing. A recent introduction, under test at the time of writing, was the American prostrate variety Rhizoma.

There is a small but increasing production of lucerne seed in the driest areas of this country, but the yield is very greatly dependent on seasonal conditions. The bulk of seed requirements are supplied from France.

As lucerne is sown down for several years it follows that it does not occupy a regular place in the rotation, but is grown as a substitute for other forage crops or meadow-hay.

By far the most important point in the preparation of the soil for lucerne is the thorough eradication of weeds. The necessity for thorough cleaning of the land cannot be overemphasised; the crop will certainly be a failure if it has to compete with weeds. Lucerne will well repay a thorough preparation, and it may be worth while to grow two successive root crops, or to give the land a bare fallow, to get it clean. Lucerne has been sown with and without a nurse-crop; it has been broadcast and it has been drilled. The modern practice, however, is to drill it without a nurse-crop, using 20 lb. of seed per acre. If it is intended to keep the crop hoed the rows must be some 10 or 12 in. apart, otherwise the best results are likely to be obtained by using the special American type of alfalfa-drill (see p. 188), which can be very accurately set at the necessary small depth and has its coulters some 3½ to 4 in. apart. It may be sown in April or, after thoroughly cleaning the land, about the end of July. A firm seed-bed is desirable and the depth of sowing should be ½ in. The object of wide drilling is to enable the land to be hoed and the weeds suppressed, and when cultivation is on a large scale this can be done quickly and satisfactorily by row-crop tractors carrying the hoeing attachment in front. In order that it may be enabled to

develop a strong root system lucerne should not be overcut during the first cropping year. Emerging seedlings may be attacked with great loss by a weevil. Early treatment with D.D.T. or B.H.C. preparations is very effective. Weeds in established crops may be controlled by Dinoseb dressing, and the same treatment, with special precautions, can be used on seedling stands.

The manuring which generally gives the best results is about 4 cwt. of superphosphate per acre, or an equivalent of some other phosphatic manure, applied to the land before seeding. On potash-rich soils potash may occasionally be unnecessary, but experiments have shown great numbers of crops to have failed for lack of sufficient supply of this nutrient. On light soils with a "low" or "very low" content of available potash up to 4 cwt. per acre of the muriate is indicated as a seed-bed dressing. It is equally important that potash be applied regularly during the life of the stand, particularly where the crop is repeatedly mown for drying or ensilage or for hay. In such cases the equivalent of 3 cwt. of muriate of potash per acre per annum may be removed. The plant shows characteristic leaf symptoms when the potash intake is inadequate. Another point is that uptake by the roots is rather slow; hence quicker response is obtained by foliar sprays, or by broadcasting a finely ground muriate on the damp leafage. This may be necessary to secure establishment of the seedlings.

The crop makes no abnormal demand for phosphate. Some growers make a small application of nitrogen in the seed-bed, but this is of doubtful value. Certainly, in the case of grass-lucerne mixtures, the application of nitrogen is inadvisable, since it would be likely to lead to suppression of the lucerne by the faster-growing grasses.

When heavy crops are removed each year it is essential that the mineral dressing should be repeated in order to maintain the fertility of the soil. If the soil is short of lime, heavy dressings should be applied before any attempt is made to grow this crop. Very often the slow development and the pale colour of lucerne can be traced to the absence of the proper nitrogen-fixing bacteria. The old remedy for this was to obtain soil from a field that had grown lucerne well and to scatter it over the crop at the rate of a few hundredweight per acre. The modern treatment is to inoculate the seed with the correct strain of micro-organism,[1] and this

[1] Cultures may be obtained from Messrs Allen & Hanburys Ltd.

should always be done when growing the crop for the first time. In many experiments such inoculation has doubled the yield and at the same time has greatly increased the protein-content of the herbage.

The persistence of lucerne depends to a great extent on the cleanness of the land at the time of seeding, and on the success of the operations for the control of weeds. The chief competitors are weed grasses—especially, in many districts, the bromes. Also the time of cutting and the building up of reserves for winter should follow the lines already indicated.

In the drier areas of North America a combination of lucerne and smooth brome grass is widely used for three or four years' pastures, and mixtures with leafy cocksfoots, meadow fescues, and timothys are being used to an increasing extent in the drier part of eastern England. Such leys require special systems of management, the main point being to avoid over-close grazing, which is apt to be fatal to the plants. The balance between lucerne and grass must be decided in relation to the climate, since in the higher-rainfall areas most grasses tend to dominate the lucerne. Common mixtures are 15 lb. lucerne with 3 lb. cocksfoot, or 5 lb. timothy, or 6 lb. meadow fescue, together with ½ lb. of one or other of the persistent types of white clover.

When seed is taken from lucerne it is the second cut that is ripened, harvested, and threshed. Cutting should take place when the seeds have hardened; the material is then dried as in making hay, stacked, and allowed to stand for some time before being threshed with a clover-hulling machine.

SAINFOIN

Sainfoin is a leguminous plant which is of some importance in the sheep districts of the south of England. It may be used for soiling purposes, but it is usually grown for hay or grazing. It is often used as a substitute for clover on land where clover-sickness is prevalent, and it forms such a healthful food that sainfoin leas are frequently used as pasturage for sick or weakly animals. Sainfoin hay is also in demand for racehorses. It produces stems about 20 in. high, is deep-rooted like lucerne, and forms strong rosettes of basal leaves which withstand hard grazing.

There are two distinct types, namely Common and Giant sainfoin. Common sainfoin is a perennial which reaches its

maximum development in about three years, and is used to sow down leas for six or seven years' duration; it differs from Giant in having finer stems, a more prostrate habit of growth, greater persistency, and the inability to flower twice per season; it produces a hay or a seed crop per season and the aftermath provides grazing, or it may be used for grazing only; it grows more slowly and produces less bulk than the Giant variety and, like lucerne, it has ultimately to be ploughed up, as it becomes very weedy. Giant sainfoin is shorter lived than the Common variety, and is cultivated as a rotation legume for one or two years in place of clover; it establishes itself quickly, produces good bulk, and as it flowers early and grows vigorously after cutting, it will produce at least two crops of hay, or a crop of hay and a crop of seed, in a season. Between the Common and Giant types is a range of intermediate strains, one example being Cambridge Common. Selecting seed from a second-flowering sort favours the Giant variety, while taking seed from a crop that has stood for several years favours the Common. There are also differences in the strains of Common grown in different parts of the country. The Cotswolds and Hampshire both produce good strains.

Sainfoin is most largely grown on the dry, chalky, and limestone soils of the Downs and Cotswolds. As it is deep rooted and drought resistant, it thrives on light land, but it will only grow where the climate is warm, and fails utterly unless the soil is well drained. It is also intolerant of acidity.

The commoner sort of commercial "seed" of sainfoin is really a fruit which contains a true seed within a light and spiny husk; it is bulky, and owing to its lightness is very difficult to harrow into the soil. However it is possible to obtain true seeds, which have had their husks removed by milling, and these are more easily handled. The land should be in clean condition before sainfoin is grown, and the crop should be seeded under a nurse-crop of barley by broadcasting or drilling at any time from early March to late April. About 56 lb. of milled seed is required per acre, but the seeding has to be increased to 120 lb. when rough seed is used. It is usual to drill the seed in rows about 10 in. apart, and in a direction at right-angles to the rows of barley.

A good manuring per acre is 3 cwt. of superphosphate and ¾ cwt. of muriate of potash applied to the nurse crop, which is commonly barley; but where Common sainfoin is down for several years, and a crop of hay is removed each season, further

dressings of phosphates and potash will be necessary to prevent rapid deterioration. Short dung is sometimes employed, but this can generally be more usefully applied to a root crop.

Although a crop of seed may be taken from sainfoin before it is broken up, the production of seed in the early years of the lea tends to reduce the persistency of the plants. Consequently, good management demands that they should either be kept well grazed or else mown as soon as flowering begins.

When sainfoin is made into hay it is cut at the commencement of flowering, and very carefully handled in order to avoid breaking off the delicate leaves. Turning can be most safely carried out in early morning when there is dew on the herbage: 30 cwt. of hay is about the average yield.

TRIFOLIUM

Crimson or Scarlet clover, generally known as Trifolium (*Trifolium incarnatum*), is an annual legume which finds a useful place in the agriculture of the south of England for catch-cropping purposes. It establishes itself very quickly, and produces a fair bulk of nutritious fodder which may be either grazed or soiled, but it develops practically no second growth. The chief disadvantage of the crop is that it is dangerous food for stock when it is over-ripe, for it produces very hairy flowers which may form balls in the intestines and cause death.

Crimson clover is successful only in the warmest English counties as it cannot survive a very cold winter; it thrives on light, firmly compacted soils. Trifolium is practically always grown as a catch-crop after a cereal has been harvested or to "mend" patches in a one-year legume ley, *e.g.* of red clover or trefoil; and it is consumed in the spring in time to leave the land clear for turnip sowing in June. It cannot be sown under a nurse-crop in spring like most other leguminous forage crops, as it will not grow again after being cut at harvest.

Sowing takes place on a stubble which has been worked into a fine surface mould without ploughing. The plant thrives much better on a firm bottom of this kind than on land which has been ploughed. The seed is broadcast at the rate of 20 lb. per acre as early in August as possible, and harrowed in. If there is rain the plants grow quickly and are firmly established before winter sets in, and if early, medium, and late varieties are sown the crop

will provide a continuous supply of forage in May and June. Trifolium is too hairy and fibrous to make satisfactory hay. Some varieties possess white flowers.

The common clovers and also Trefoil are discussed in Chapter VIII. Two other species that may be worth mention are Sweet Clover and Serradella. The former is widely grown in North America. It is quick growing and productive, but very woody. Serradella, like the lupins (and unlike most of the legumes), is highly tolerant of acid soil conditions. The early types were of little value under British conditions, but new and improved German selections might be worth a trial.

CABBAGE

The cabbage is a cruciferous forage plant which, along with broccoli, brussels sprouts, and many allied species, has been obtained by a long process of selection from the wild cabbage, *Brassica oleracea*. It is one of the more important forage crops cultivated in this country, and is grown to a greater or less extent in almost all arable farming districts. Cabbages may be safely fed to all classes of stock, and being mild in flavour, do not taint milk unless fed in very large quantities; they are useful as green food for pigs and poultry, and are largely used when cattle and sheep have to be maintained in show condition; they may be folded with sheep and are superior to turnips and mangolds in feeding value, and if suitable varieties are grown they may be sold for human consumption. A great advantage of the cabbage is that it can be safely fed whether mature or immature. If the stems and basal leaves are left in the ground when the crop is cut, fresh leaves and buds will form and will provide a further supply of food suitable for sheep; on the other hand, the final residue of stems is slow to decay and difficult to dispose of. Cabbages have the disadvantage that they cannot be harvested and stored like roots, and the flat-topped varieties are susceptible to a certain amount of decay if left standing for prolonged periods of wet weather. In late summer pasture grass deteriorates greatly in yield and nutritive value, and cabbages may be most usefully employed as a supplementary feed for stock during this period.

Varieties.—Cabbage varieties differ in appearance, size, hardiness, and the time required for their development. Although cattle cabbages are coarser than the ordinary garden sorts there is

no hard-and-fast distinction between the two types, and garden varieties are frequently grown on a field scale. Cabbage varieties are very numerous, but they may be roughly grouped in the following way:—

1. *Late or Maincrop Varieties*.—These are large cabbages which require a long time to reach full size; indeed, from seeding to cutting they may occupy ground for well over a year. The largest, such as Flatpolls and Drumheads for stock feeding, may require a square yard per plant to allow for their full development. Other kinds, for example some varieties of Savoys, are grown in 2- to 2½-ft. drills and planted at intervals of up to 2 ft. The seed is sown in a bed during August and the plants are normally left there over winter and planted in April. The time when the cabbages are ready for cutting depends on the district and the variety, but maincrops are primarily intended for late autumn and winter use. When the varieties in this group are sown in March to April for transplanting in May to June they are unable to attain full size and are consequently more closely spaced. They are fit for cutting very late in the following winter.

2. *Autumn-sown Early Varieties*.—Early varieties are often sown in July or August and planted out in September with the object of supplying the spring cabbage trade. They may be planted 1 ft. apart in 1-ft. rows. Alternate plants may be removed in March or April and sold as "greens," the remainder being cut and sold as soon as they are well hearted. Wider spacing is adopted for crops that are to be marketed later. Suitable sorts for this purpose are Sutton's April, Flowers of Spring, Enfield Market, and varieties of the Early Offenham type.

In some districts certain varieties normally sown in spring are sown during August, wintered in the seed-bed, and transplanted in April. When a hardy early variety such as Winningstadt is treated in this way it may be ready for cutting in July.

3. *Spring-sown Varieties*.—These may be sown from March to April and planted out in May and June. Early sorts will be ready for cutting or feeding in August, and may be spaced 1 ft. 6 in. to 2 ft. each way. In order to avoid the set-back of transplanting, the earliest varieties may be drilled in 18-in. rows and singled. Sometimes early cabbages are planted in July after a forage crop that has been removed in June or after early potatoes, and for this purpose the seed should be sown in May. The most forward plants will be ready for use in October, and the remainder

may stand out until the end of the year. Early Drumheads and Winningstadts are suitable varieties in this class. Later varieties will be ready for cutting in winter.

Although approximate dates of sowing, planting, and harvesting certain varieties are mentioned above, it should be remembered that much depends on local conditions, and the custom of the district had better be followed until experience of the crop has been gained. Cabbages are irregular in the time taken to reach their full size, and it is generally most profitable to cut the best plants and allow the smaller ones further time to develop. By using summer, autumn, and spring sown varieties of different degrees of earliness it is possible to secure a supply of cabbages all the year round.

CULTIVATION

Soil and Climate.—The cabbage is a typical heavy-land crop and attains its greatest perfection on strong clays that contain plenty of lime. However it grows well on light soils which have been given body by dunging. Light soils are essential for spring cabbages, which attain the necessary development for early marketing only on warm, free-draining land. The crop thrives anywhere in Britain and resists drought when once it is well established; but it does not start well unless it gets a good deal of rain, and in a dry climate is less resistant to parasites.

Place in Rotation.—Cabbages occupy the same place as roots in the rotation, and replace turnips for early feeding in districts where the mangold is the staple root crop. When planted regularly and wide apart, cabbages offer even greater facilities for cleaning the land than do roots. Planting may be done "on the square" so as to allow horse-hoeing in two directions, and hand labour is thus reduced to a minimum.

Preparation and Planting.—The most important sowings take place in late July and August; too early seeding may result in a proportion of the plants bolting. A piece of good land in a sheltered spot is selected for the bed, and the soil is reduced to a fine tilth by ploughing and harrowing. In order to stimulate the growth of the young plants about 3 cwt. of superphosphate may be applied, and the seed is put in with a hand-drill in close rows at the rate of 20 lb. per acre. The whole should be well harrowed in and then rolled. An acre bed will grow enough cabbages to plant about 20 acres in the field, the exact number of plants

required being, of course, determined by the intervals of planting. If the raising of plants cannot conveniently be carried out, or the climate is too severe for the plants to withstand the winter, cabbages of suitable size may be purchased from farmers who specialize in this business. Cabbages may be sown with a drill like an ordinary root crop at the rate of about 2 lb. of seed per acre; and although the plants get a later start, and the cost of singling is as much as that of dibbling, some growers in dry districts adopt this practice to avoid the set-back of transplanting.

The ground is prepared in exactly the same way as for root crops, and the cabbages may be planted in any of the following ways:—

1. The field may be drawn up into ridges 24 to 30 in. wide in the same manner as when preparing for roots, and the plants dibbled along the ridge tops. When dibbling young cabbages care should be taken not to bend the tap-roots, and the plants should be buried so that the leaf bases are covered, as this gives them a much stronger hold in the soil. Moreover, damp weather should be chosen for planting, and in a garden water should be used and the plants set in plenty of "puddle." The plants should be "heeled" so that the soil is pressed firmly about their roots.

2. On free draining soils which are used for growing spring cabbages the plants may be set along the bottom of shallow furrows which are opened by a double-mould-board plough. The object of this is to provide shelter from frosty winds.

3. When cabbages have to be planted in dry spring or summer weather, good results may be got by dibbling the plants into the middle of freshly turned furrow-slices. The object of following the plough closely in this way is to set the plants in the dampest and firmest portions of the soil.

4. Cabbages may be laid by hand along the side of every third furrow-slice, so that their roots are covered by the soil turned over by the next plough. This is a quick method, but as the soil is not firmly pressed about the plant roots it is not very satisfactory in dry weather.

5. Cabbages may be planted on the flat after the soil has been ploughed, cultivated, harrowed, and rolled. Before this takes place the land must be marked off. A marker can be made by fitting short tines to a suitable framework, but even a seed-drill can be used if its coulters are set to the desired intervals. If the

marker is taken across the field in two directions, the one at right-angles to the other, it becomes possible to space out the plants on the intersecting marks so accurately that horse-hoeing can be carried out in both directions, and very thorough cleaning effected.

6. The crop may be put in with a planting machine (see p. 228).

7. The seed may be sown in rows where the crop is to be grown, and singled in the same way as roots. The quantity of seed required is, of course, much increased, and cabbage seed is rather costly. Moreover the crop occupies the ground for a longer time. On the other hand, the method avoids the risk of failure in transplanting, which is a serious one in the drier areas, especially where the job falls to be done in late May or in June.

As with practically all crops, the optimum area for each plant depends not only on the variety but on the quality of the soil; wider spacing will be required on richer land. In almost every case early planting produces a distinct improvement in the yield.

Manuring.—As cabbages have a long growing season and are capable of producing an enormous weight of dry-matter per acre, they should be manured with great liberality. The crop is sometimes said to be a gross feeder, but this must be reckoned as a point in its favour; its capacity for responding to fertilizers fits it for the most intensive types of farming. Farmyard manure is the basis of all dressings and may be ploughed in at the rate of from 15 to 25 tons per acre. On heavy land 2 cwt. of superphosphate, 2 cwt. of steamed bone flour, and 1 to 2 cwt. of sulphate of ammonia may be applied at planting time; in addition, 2 or 3 cwt. of nitrate of soda applied in two or three dressings during the growing season will prove beneficial; indeed under favourable conditions, nitrogen fertilizer up to the equivalent of 6 cwt. sulphate of ammonia per acre can give a profitable return. On light land 1 cwt. of sulphate of potash may be applied in addition to the above dressings, except, perhaps, where very large dressings of dung have been given. It pays to apply the nitrogenous top-dressing to cabbages by hand, and this is done by dropping a little of the fertilizer around the stem of each plant. Broadcasting may, of course, be practised, but owing to the wide spacing of the plants much of the fertilizer applied in this way never reaches the roots and is lost, and that which falls on the leaves causes a certain amount of scorching of the tissues.

The subsequent management of the crop consists in the usual horse and hand cleaning operations, and in filling any blanks by means of seedlings, which should have been retained in a bed for this purpose.

Where cabbage root fly is troublesome, 4 per cent. calomel dust should be applied round the stems about the end of April or when setting out the plants at a later date. About $\frac{1}{10}$ oz. per plant is sufficient, but a second dressing should be given three weeks later. The caterpillars of the white cabbage butterflies may cause serious damage unless control measures are applied in time. A variety of effective sprays and dusts are available including a dust containing 5 per cent. of D.D.T.

Securing the Crop.—Many attempts have been made to store cabbages and retain them for late use, but the methods are too costly to be worth consideration and the practice cannot be recommended. The crop is best left in the field until it is needed for stock. Unless the land is wanted immediately the plants should then be cut so that the large bottom leaves remain on the stem. This method of cutting retains a number of buds, which will sprout and provide a very useful bite for sheep later in the season. If decay is to be avoided an endeavour should be made to have a mature crop used up before the end of the year.

On good land maincrop market varieties yield 15 tons and upwards per acre. On the other hand, spring cabbages, cut as small, early greens, may produce only 3 or 4 tons per acre. With fodder varieties 20 tons per acre is often exceeded.

RAPE

Rape is sometimes grown for its oily seeds (see p. 404), but its main use in this country is for forage purposes and generally as a catch-crop. There are two types, botanically closely related to turnips and swedes respectively, but producing no bulb. The swede-like type is the one commonly grown in Britain. In the south the crop is liable to suffer from mildew when sown early, and it is most popular in the damp and cool districts of the north and north-west. It may be cut for soiling, but is more usually folded with sheep, and for this purpose it may be grown in mixture with Italian ryegrass. It is also sometimes used as a nurse-crop for grass seeds where cereals are unsatisfactory for this purpose. In this last case only 3 or 4 lb. of seed should be used.

The varieties commonly grown for fodder are winter hardy biennials, *i.e.* they flower and set seed in their second season. There are a number of varieties of the ordinary swede-like rape, tall-growing early sorts that are not highly frost resistant, later and dwarf varieties, and the highly frost resistant rape-kales such as Hungry Gap and Fill Gap which are useful for folding in March and April.

Rape is usually broadcast at the rate of 10 to 12 lb. of seed per acre, but if drilled in rows 10 or 12 in. wide, 3 or 4 lb. less seed will suffice. Sowing may take place at any time from May to about the middle of August, and as the crop is second only to mustard in the rate at which it attains maturity, it may be grown after any crop that has been consumed, or removed in spring or early summer. It is particularly useful if the land cannot be got ready in time to sow turnips.

Under average conditions a yield of 10 tons per acre may be obtained.

KALE

Kale is now regarded by many farmers as the most valuable of all arable fodder crops for cattle; and it is true that, when properly grown and fully fertilized, it can produce as high a yield of nutrients (starch equivalent and protein) as any other crop species.

Kale belongs to the cabbage tribe, and is for all practical purposes a tall-growing cabbage with spreading foliage which forms no heart. As a home-grown food for stock it has to be compared with cabbages on the one hand and swedes on the other. While it is susceptible to the cabbage parasites, its open habit of growth, which prevents the lodgment of water, makes it more resistant to winter conditions, and although from January onwards it is apt to suffer loss owing to the withering of leaves, the hardier types may be allowed to stand out until spring in the milder areas. As compared with the swede, which it has largely replaced in many districts, it shows a much greater response to fertilizers, especially to dressings of nitrogen. Moreover it withstands drought better and makes a quicker recovery when rain comes; it is also far more resistant to a number of parasites, including finger-and-toe disease. Against these advantages over the swede, it cannot be stored except as silage, and when it does stand out it suffers more loss. Some feeders also find that, as the

stems may become rather fibrous or woody, the crop as a whole is not as completely eaten as are roots.

Regarding the relative proportions of the different parts of the plant, marrow-stem kale has on the average rather more than 50 per cent. of its weight in the stem, 15 to 20 per cent. in the petioles (leaf stalks), and 20 to 30 per cent. in the leaf blades. In quality the leaves are greatly superior to the stem; they contain about twice the protein, three times the ether extract, about as much nitrogen-free extract, and the greater part of the ash. The petioles are intermediate in composition, often more nearly resembling the stem.

Kale may be soiled for cows, cattle, or pigs, or it may be folded with sheep. The practice of folding dairy cows on the growing crop is now common, especially on the lighter sort of land in the milder parts of the country. A single electrically charged wire, carried about 2 ft. 6 in. above ground level, is used to confine the cattle. The daily fold should be a narrow strip, long enough to allow about 3 yds. per cow and wide enough to provide the daily allowance, which is ordinarily some 40 to 50 lb. This amount will be consumed in little more than an hour. Folding is ordinarily done after the morning milking. The preparation of the daily fold can be done in perhaps an eighth of the time that would be required to cut and cart the daily requirement. Kale probably gains in dry-matter up to November, and as pointed out above, it tends to lose both bulk and quality in the latter part of winter. The crop is lifted by cutting through the stems above the woody portion and the plants may be fed whole or chopped. Not only is kale a safe and satisfactory forage crop for milch cows, but the carotene which is present in the leaves gives milk a rich colour and a high vitamin-content. Many dairy farmers therefore use kale throughout the winter, 15 to 20 lb. of leafy material per head per day being sufficient to maintain a very fair colour. Kale is given to fattening and other cattle in place of roots, and to pigs as a succulent which is also a source of vitamins and minerals. When kale is used for feeding sheep the best results are likely to be got before it begins to deteriorate, that is, before the end of January. In the south of England, however, it is very common to drill swedes and kale in alternate strips and to use the crop in January and February for flocks during and for some time after lambing. Indeed an elaborate succession of (1) turnips, (2) kale, (3) swedes and kale,

and (4) swedes alone, is often planned for wintering the sheep, but some farmers use only turnips and the swede-and-kale mixture. Chopped kale is easy to make into silage without the addition of acid or molasses, but the process entails a very considerable loss of nutrients. It is probably wise, in most districts, to ensile that part of the crop that is not likely to be consumed by Christmas, but opinion is divided on the comparative merits of kale silage on the one hand, and swedes and mangolds on the other, for late winter and spring use.

Thousand-headed kale and marrow-stem kale are the best known varieties, the latter being thicker in the stem, taller, and more responsive to rich soil and favourable climate; but grown side by side on poor to average land the two sorts are very similar. Thousand-head is the hardier of the two and is therefore used for late winter keep. The seed is usually sown in April [1] at the rate of 4 lb. per acre in drills 18 or 20 in. apart. As a rule an unsingled crop gives a greater total yield than one that has been thinned, and at least as high a proportion of leaf, and it is therefore preferable for sheep; but a singled crop is more convenient for cutting and carting. A suitable interval between the plants is 10 to 12 in. Kale should be manured in the same way as cabbages and is quite as capable of responding to liberal treatment; indeed a fertilizer such as Nitro-chalk, if applied in several dressings, can be used at a rate of 4 to 6 cwt. per acre. Such generous treatment, however, lowers the plant's resistance to frost and should not be applied to crops for late winter use. Drill cultivations can be performed throughout the early part of the growing season, but should be no more than are necessary to check weeds. Deep working between the rows is likely to damage the roots and do more harm than good.

While kale is most commonly grown as a row crop, many farmers in the wetter areas sow broadcast, either alone or in mixture with Italian ryegrass. The common practice is to sow in summer for the production of winter grazing. This mixture, and also one of rape and ryegrass, are used as "pioneer crops" in the reclamation of hill land (see p. 483).

[1] In those areas where turnip fly is a major problem it has been the custom to sow part of the crop in late March and a further part in late May. The seedlings thus escape the major attack of the fly, which ordinarily occurs in mid-May. Since, however, highly effective flea-beetle dusts are now available, it may be well to revert to April sowing and to apply dust as a routine measure.

In certain seasons, especially when crops of spring cabbage have been destroyed by winter weather, there is a good demand for kale tops in March and April for human consumption. In such cases it may be very profitable to pick over a field of late kale before folding with sheep.

The weight of crop per acre, of course, depends on the soil, climate, and manuring. Even on poor land yields of 10 or 12 tons can be got without much difficulty, while under favourable conditions yields of 20 to 30 tons are not uncommon.

MUSTARD

White Mustard [1] is a cruciferous annual which is commonly grown as a catch-crop. It may be used for green manuring or folding with sheep, and it has a high reputation for "flushing" ewes. Its most valuable characteristic is its very rapid growth; on good land it may attain a height of over 2 ft. in less than a couple of months. It is often grown after a crop of early potatoes, and is useful for conserving the residues of the heavy dressings of manure applied to this crop.

The seed may either be broadcast at the rate of 20 lb. per acre or sown in 12 in. drills at the rate of 15 lb., and seeding may take place at any time between early spring and the month of August. However if the crop is to be eaten off it must be consumed before winter, as the plants are not sufficiently hardy to withstand frost. When mustard is grown for green-manuring, and the plants are tall, it is necessary to attach a drag-weight and chain to the plough in order to roll the long material under the furrow; indeed it may also be desirable first to roll the crop according to the scheme of ploughing so that the plants lean in the direction of travel.

White mustard is also grown for its relatively large seeds, which are ground and mixed with the product of brown or black mustard in the manufacture of the ordinary condiment. There is also a considerable sale of seed for the production of green (seedling) "mustard and cress."

Brown Mustard [2] is not grown for forage, but is rather widely cultivated in Norfolk, Cambridge, and Lincolnshire for its seed. Production is chiefly on contract for the manufacture

[1] *Sinapis alba.*
[2] *Brassica nigra*

of condiment. The common variety is Native English, which may yield some 8 or 9 cwt. of clean seed per acre. One objection to the crop in the past has been that it often sheds seed during harvest and becomes a weed, but self-sown plants are as easily destroyed as charlock. Some types of the species have black seeds and are commonly called "black mustard." Properly speaking, **Black Mustard**[1] is a separate species. A short non-shattering type of this, called Trowse, has been bred, and may probably displace the brown types hitherto grown for condiment manufacture. Its main advantage is its higher yield—perhaps 14 cwt. per acre as against 8 or 9 cwt.

Brassica Vegetable Crops.—Numbers of farmers, especially in the eastern counties, regularly grow large acreages of Brussels Sprouts and Cauliflower, in rotation with cereals, etc. In mild districts Broccoli is also grown, often following early potatoes. Information may be obtained in such standard works as *Vegetable Crops for Market* by Hoare (Crosby Lockwood).

MAIZE

Maize originated in America and very soon after the discovery of the New World spread very widely throughout Africa, southern Europe, and southern Asia. In this country even the earliest varieties have been found to ripen seed only in the warmer years and in the sunniest and hottest districts such as Kent, Essex, and Suffolk, but continuous progress in the direction of earlier maturity is being made in the northern United States and Canada, and new strains are being tested in the south of England. The sweet varieties are grown on a small scale for table purposes and some of these can produce ripe seed with fair regularity in the south-east of England.

In Britain maize is one of the minor forage crops for use in the late summer. For this purpose it should be cut when the grain is well formed but still pasty in consistency. Many of the newer hybrids easily reach this stage of development in the south-eastern half of England. In fact, however, they were little grown for fodder purposes at the time of writing. The leaves are readily killed by slight frost and the crop is not worth trying in districts where even slight summer frosts are liable to occur. Its greatest value is to dairy farmers in dry areas where pastures often produce

[1] *Brassica juncea.*

little growth during August and September. If it is not required for soiling it can be made into excellent silage.

Maize grows best on warm, fertile loams, but when well manured it produces good crops on light soils, provided that these are of fair depth. Light soils have the advantage of warmth and earliness; on clays it often fails to reach the best stage of maturity.

In the past the most popular variety has been American White Horse-tooth, which is a vigorous grower but which in England never reaches the best stage of maturity for ensilage. It is essential to procure seed of tested germination, because the grain may often be damaged by frost, before harvest, in the areas where the early varieties are grown.

The crop is generally grown on land that has received a good dressing of farmyard manure, and at seed-time it is given about 2 cwt. of sulphate of ammonia, 3 cwt. superphosphate, and 1 cwt. muriate of potash per acre. A deep seed-bed is prepared by harrowing, rolling, and cultivating, and in mid-May the seed is drilled in rows from 18 to 24 in. apart, at a depth of about 2½ in., and at the rate of about a bushel per acre. The minimum temperature for germination of the seed is higher than that required for the general run of British crop plants, and if sown in cold soil the seed will rot. Dressing the seed with T.M.T.D. dust may prevent this. Special measures are necessary to protect the seed from rooks.

After sowing, the crop is harrowed to suppress weeds, horse-hoed as often as is necessary or practicable, and sometimes hand-hoed. If sown thinly there is no need for singling. The maize grows rapidly and a good crop soon checks weeds by shading.

The crop is cut by hand as required in late August and September, loaded into carts, and driven on to the pastures. It must be put through a chaffer and blower if it is to be made into silage. The yield varies from under 10 to well over 20 tons per acre.

The production of ripe grain from early maturing hybrid types of American and Dutch origin was being attempted at the time of writing in the south-eastern half of England. While useful crops of ripe grain had in fact been produced, it was still too early to predict whether commercial production would be profitable. The advantages of the crop over barley would be its

larger yield and its adaptability to row-crop cultivation—*i.e.* it might replace fodder roots in the rotation.

SOILAGE

Soilage is the practice of feeding animals on cut green forage. In an extreme case the stock may be kept in confinement throughout the year; more commonly forage crops may be cut and used to supplement the pasturage at the beginning and end of the grass season or in periods of summer drought. The advantage of soiling stock is associated with the greater productiveness in the drier areas of arable crops over grass, and a properly designed soilage system enables a larger head of stock to be carried on a given acreage.

Advantages of Soilage.—The advantages of soilage over the ordinary method of keeping stock on mixed arable and grass farms are as follows:—

1. When a plant is kept closely grazed its leaf surfaces are reduced to a minimum and its power of synthesizing foodstuffs is diminished to a corresponding degree. Moreover, frequent defoliation reduces the plant's root system and therefore its power to resist drought.

2. With many farm crops the longevity of a species is opposed to its productiveness, *e.g.* Giant sainfoin is a heavier cropper than the perennial Common variety. Under arable conditions it is possible to select the most productive species, and the length of life is immaterial provided that one good crop can be obtained. For permanent pasture, however, the selection of lasting species is essential even if they are relatively poor producers.

3. The plants are not damaged by being trampled and broken by stock or fouled by manure, and certain parasitic troubles are avoided.

4. In hot weather and during the "fly" season, when so many animals lose condition, stock may be comfortably housed so that they go on producing substantial gains, and there is no falling-off in the milk yield of cows. In wet or cold weather the advantages of protection are equally obvious.

5. It is possible to cultivate a bigger proportion of the land by doing away with such expensive structures as fences and other field boundaries, and the removal of these shelters for weeds and

vermin results in bigger and cleaner crops. There is no need to have watering-places all over the farm.

6. With a well-arranged sequence of soiling crops the animals receive abundant and suitable fodder all the year round, and neither milk-production nor live-weight increase is affected by drought or by the reduced feeding value of pasture towards the end of summer.

Disadvantages of Soilage.—In order to understand soilage as an economic proposition its merits should be compared with its chief disadvantages, which are as follows:—

1. More labour is required not only for feeding the stock but for the intensive arable farming necessary for the production of a sequence of forage crops throughout the year.

2. In order to justify this extra labour a very large head of stock must be carried on the farm, and this requires extra capital and accommodation.

3. The sequence of crops required for feeding the animals necessitates periodical seedings during the greater part of the year, and long periods of wet or dry weather may so seriously interfere with these operations that one or more of the crops is missed and a food shortage may result. Moreover, when crops are seeded at odd times the ravages of birds assume a serious aspect, since, when no other sowing is going on in the district, these creatures give the seed their undivided attention.

4. The forage must be cut daily in order to avoid losses through fermentation and moulding, and this is difficult to carry out in bad weather.

5. When crops are grown in close sequence the soil is liable to become very dry, and in localities of low rainfall this results in difficulty in getting the seed to germinate and in diminished yields.

The cutting and carting of green-stuff is of course laborious, and at modern wage-rates is in general too costly where hand labour is used. But modern machines such as the "Cutlift" and the forage harvester (see pp. 201-202) may make for economic production. Moreover, the task must sometimes be done when other work is very pressing. Even when pasturage must be supplemented by the produce of arable land the alternative of folding the animals on the growing crop by means of an electric fence (see p. 422) will often be preferable. Provision of green-food for indoor pigs, for cattle and sheep that are being prepared for

show or sale, and for the few remaining town dairy herds, is commonly made in the form of soilage. Otherwise, the practice is now restricted to dairy farms in the dry areas, where pastures are liable to give out during July to September. Common crops for soiling are clover, mixtures of cereals with peas or vetches (either autumn or spring sown), maize, and early sown marrow-stem kale.

Most crops grown for soilage may be ensiled if it happens that they are unwanted at the time they are ready.

CHAPTER VIII

GRASSLAND

IT is a point of more than historical interest that most of Britain's grasslands—including even moorland grazings—are in some degree artificial. The truly natural grasslands of the world—for example, the American and Canadian short-grass prairies—occur in regions that are much drier (taking both rainfall and evaporation into account) than any part of Britain, *i.e.* are too dry to support forest. Such natural grasslands are of low productivity—chiefly because it is only during short periods each year that the soil is moist enough to support active growth. Typical range country of this kind has a carrying capacity of the order of a breeding cow to every 20 or 30 acres. Such areas, unless the soil is very light or the rainfall very erratic, are much more productive under drought-resistant arable crops such as wheat, sorghums, and sunflower than under grass. Moreover, lucerne, where it can survive the winter, gives much higher yields than the native species. Most of the world's highly productive pastures—for example, the best dairy pastures of New Zealand and the Netherlands, or the fattening pastures of the English Midlands or the Norfolk Broadlands—have been created out of deciduous forest or out of marsh.

The native vegetation of the well-drained lowland areas of this country is deciduous forest, mainly oak-wood,[1] with smaller areas of beech and ash, associated with a " brown-earth " soil. In lowland swamps with black fen or peat soils the typical association is alder carr. In the wetter uplands, with their higher rainfall and highly podzolized acid soils, the natural association is pine-and-birch wood, degenerating with increasing altitude into scrub and petering out, at about 2000 ft., into upland moor.

As might be expected, the grasslands that have been established under these several conditions depend for their maintenance upon

[1] Such terms as " oak-wood," " pine-wood," and " alder carr " do not, of course, imply pure stands of the named species but refer to the dominant plant in each case. Thus oak-wood has a " top storey " of oak and other deciduous trees with a " shrub layer " of holly, hawthorn, etc., often some blackberry and bracken, and a ground layer of shade-bearing grasses and other herbs.

continuing human action. For instance, if drainage, manuring, and liming are neglected, and the land is understocked, a Midland pasture on clay soil will revert to scrub and eventually to oak-wood. Close grazing and mowing are the chief means of preventing the establishment of seedling shrubs and trees, while it is the use of lime and phosphate that prevents the replacement of the better grasses and clovers by heathers and other moorland species. In either case, of course, deterioration is gradual. Thus a clay pasture, undergrazed and never mown or fertilized, may first be invaded by such shrubs as bramble, wild rose, and hawthorn, which are avoided by grazing animals. Under the protection of such thorny shrubs appear seedlings of ash and other trees, whose seeds are wind-borne. Later come oak and beech from seeds that are carried by birds, and in the end oak-wood will become re-established. On highly podzolic soils gorse, broom, ling, and bracken will lead the invasion and the "climax" vegetation will be pine-wood.

Although the distinctions are by no means clear-cut, grazing lands may be usefully classified into three main groups. First are the *semi-natural* types whose constituent species have not been sown and whose flora has been little influenced by such major improvements as liming, drainage, and the application of fertilizers. In other words, the only measures of human interference are the control of the grazing animals with perhaps occasional mowing or burning. The second group are the improved permanent grasslands where, again, the constituent herbage plants have not been sown, but where the composition of the sward has been largely modified, and is maintained, not only by relatively close control of grazing and perhaps mowing, but also by such measures as drainage, the use of lime and fertilizers, the spudding of weeds, and perhaps surface cultivation. Thirdly are *artificial* grasslands, or leys, where the herbage consists mainly or largely of plants that have been sown.

SEMI-NATURAL GRASSLANDS

Sand Dunes.—Sand-dune conditions are unsuitable for tree growth, partly because the seedlings are apt to be smothered by blown sand or to have the soil removed from their roots; partly because of exposure to wind itself; and partly also by reason of the very low water-holding capacity of the soil. In

"young" dunes the commonest dominant species is marram grass (*Ammophila arenaria*), though occasionally it is sea lyme grass (*Elymus arenarius*). Marram does not form a continuous sward and is of very low nutritive value. Older dunes are generally invaded, to a greater or less extent, by sand fescue (*Festuca rubra arenaria*) which is a sward-builder and fairly useful feed. Sand sedge (*Carex arenaria*), which often accompanies the fescue, is also useful. Among the commoner herbs are the hawkweeds and ragwort, the latter of which is poisonous when eaten in quantity. Sand-dune grazings, while of low value for most purposes, provide useful wintering for hill sheep.

Salt Marshes—*i.e.* coastal mud-flats that are inundated only at spring tides—provide excellent pasturage upon which stock (especially sheep) fatten quickly. They are notably healthy and, unlike many fresh-water marshes, are free from liver-fluke—for the reason that the second host of this parasite is a fresh-water snail. In marshes that are closely grazed, sea manna grass (*Glyceria maritima*) usually dominates the areas of heavy silt, with sea fescue (a form of *F. rubra*) on the drier and sandier patches. Both are highly nutritious. There is usually a variety of other salt-tolerant species, such as sea lavender, sea plantain, and thrift, which are readily eaten by sheep. When the spring tides are excluded by embankments the salt-tolerant species quickly give place to the usual good pasture plants, and many ryegrass-clover fattening swards have been produced by this means alone.

Chalk Downs, especially where the soil is thin and the grazing has been mainly by sheep, carry a very characteristic close and springy sward. Under hard grazing the two small fescues, *ovina* and *rubra*, are often co-dominant, but on specially dry sites only the former contributes much to the sward. The little sedge *Carex flacca* is often the next most common species. Other frequent and not unuseful grasses include the common, the downy and the golden oats, the small (diploid) form of timothy (which has yielded the S. 50 pedigree strain), crested-hair-grass (*Koeleria cristata*), and sweet vernal. Common bent, which associates with sheep's fescue in most swards of the dry uplands, is very rare on the chalk. Two weed grasses that intrude when grazing is neglected are erect brome and tor-grass (*Brachypodium pinnatum*); typically the former is dispersed through the sward, while the latter tends to choke out all

competitors and to form expanding patches which are conspicuous because of their very coarse leafage and pale yellow-green colour. Among common legumes are bird's-foot trefoil, kidney vetch, and horse-shoe vetch (*Hippocrepis comosa*). White clover is abundant or sparse according to the phosphate status of the soil, and spreads rapidly after a dressing of basic slag or other appropriate form—ground mineral phosphate being, however, quite ineffective. There is a striking abundance of miscellaneous herbs which, however, vary from one area to another. Burnet, ribwort, the hawkbits, thyme, rock rose, and in places dropwort are very common. Common shrubs are white-thorn and juniper.

Downland pastures, though their productivity is not high, suffer less from drought than might be expected. Moreover, they can carry cattle as well as sheep in winter without hurt to the sward. Unless the soil is excessively thin (as it usually is on the steeper slopes) marked improvement can be achieved by the use of phosphates alone or of phosphate and potash in combination. Moreover, large areas of downland have, in recent years, been profitably converted into arable land. Earlier attempts at reclamation often failed for lack of the heavy dressings of potash that may be required, many of the soils being not only potash-deficient but having a marked tendency to fix the element in unavailable forms, so that small applications may produce little or no response.

The thinner soils of the limestone uplands—oölite, mountain limestone, etc.—produce semi-natural swards with some resemblance to those of the downs. But since most outcrops of these occur in relatively cool and moist parts of the country, patches of acid soil are more common. Under moderately acid conditions common bent is often co-dominant with sheep's fescue, while more extreme soil acidity is reflected by the presence of such heath species as tormentil and lady's bedstraw (*Galium saxatile*).

Lowland Sandy Heaths are exemplified by the Brecklands of Norfolk and Suffolk, and occur in many other areas such as the New Forest, the Bagshot sand district of the Thames Basin, and Sherwood Forest. Even under low-rainfall conditions coarse sands and gravels become heavily leached and therefore very acid, so that extreme podzolization, with the formation of "iron pan," is common. The soils are very poor in plant nutrients as well as in lime. Bracken is very common, but grows strongly only on patches of relatively heavy and not extremely acid soil.

Common heather (ling) and purple bell-heather (*Erica cinerea*) are co-dominant over wide areas but (by contrast with upland and northern moors) bilberry is rare. The dwarf-gorse (*Ulex minor*) occurs in patches. A saying of the old improvers was " copper under heather, silver under gorse, and gold under bracken." The commonest grasses are bent and wavy hair (*Deschampsia flexuosa*).

As might be expected, the grazing value of typical sandy heath is almost negligible; moreover, ploughing-out and re-seeding, which is a successful method of improvement in the wetter uplands, gives poor results since the better long-lived species of grass are unproductive under the dry conditions. The less poor land has, of course, largely been converted to useful arable, and some that was formerly thought to be incapable of economic reclamation is now being successfully farmed on a system whereby lucerne or lucerne-cocksfoot leys are alternated with barley, sugar-beet, etc. Afforestation, particularly with Scots Pine, is in many cases the only profitable form of utilisation.

Mountain Grazings.—Upland and mountain regions, by reason of their short growing season and their heavily leached and therefore acid soils, have more or less severely limited agricultural potentialities, so that costly improvements—drainage, fencing, liming, and the clearing of boulders—are often ruled out on economic grounds. The common choice is between afforestation and extensive sheep farming.

The plant associations found under pastoral conditions depend upon such factors as the type—acidic or basic—of the underlying rocks, the elevation and aspect, the combination of grazing stock (sheep, cattle, and hill ponies), and the frequency and severity of burning. Five main associations may be distinguished :—

Heath is typically dominated by common heather or ling (*Calluna*), though bilberry and bell heather (*Erica cinerea*) often form large patches. Ling provides useful sheep keep, especially in winter and early spring, but is rarely eaten by cattle. Bilberry is of very little value. The heath association occurs where rainfall is high but drainage fairly good and where the soil is very acid. Many of the plants, including common heather, depend for their nutrition upon a symbiotic root fungus (*Phoma*) which cannot live under alkaline conditions. Moreover, heather cannot survive under continuous close grazing. Bell heather tends to dominate on the driest sites. The heaths are generally interspersed with grasses, the commonest species being wavy hair (*Deschampsia

flexuosa), *Nardus* (mat grass, wire gràss, or white bent), and *Agrostis*, one or other of which may become dominant when an old stand of heather is destroyed by burning. Heather is " browsed " rather than grazed by sheep—*i.e.* only the tips of the shoots are eaten ; these contain a surprising amount of calcium. *Nardus* is the main species on the so-called " white land " of mountain grazings. The name " mat grass " derives from the fact that its rhizomes give rise to a tough mat of raw humus, and the name " wire grass " indicates the character of the leafage. *Nardus* occurs under the same conditions as heather, but colonizes much more rapidly from seed ; hence, as said above, it often succeeds heather when the latter is killed—*e.g.* by burning an old stand in very dry weather. The spring growth of *Nardus* is reasonably nutritious, and the tufts of dead leaves are accessible at times when lowlier herbage is covered with frozen snow. Otherwise the value of " white land " depends largely upon the proportion—never very large—of other species with which the *Nardus* is associated. The commonest of the grasses are sheep's fescue, wavy-hair grass, sweet vernal, and, under the better conditions, *Agrostis*. The common herbs of acid uplands are tormentil and bedstraw.

Flying bent or purple moor grass or blae grass (*Molina caerula*) becomes dominant under wet conditions—*e.g.* at the foot of slopes and in depressions—but is not found in deep stagnant bogs ; it seems to favour sites where the ground-water has a relatively high mineral content.

Molina provides abundant and relatively nutritious grazing in the early summer, and is the main constituent of the hill shepherd's " bog hay." The leaves, however, break off in late summer and are so light that they are easily blown away. The grass therefore provides very little keep during winter.

Bent-fescue.—Apart from " flush " land, which is mentioned below, this is the most valuable association found on hill grazings. *Agrostis* tends to dominate the wetter areas and sheep's fescue the drier. Soil requirements are somewhat the same as for heather —*i.e.* a relatively well-drained site and a soil reaction about *p*H 4 to 5. But the grasses tolerate close grazing, and hence replace heather in areas where the sheep congregate or which they often traverse. Bent-fescue swards often contain suppressed plants of white clover, and an application of phosphate will often induce change to an *Agrostis*-clover sward.

Bracken, although originally a woodland plant, grows most vigorously in full light, and is mainly found on sheltered slopes and in valleys, on land which would otherwise carry an *Agrostis*-fescue sward. It is fully vigorous up to elevations of 1000 or 1200 ft., but extends in places up to 1500 ft. and occasionally higher. It will not grow on heavy clay nor on shallow soils overlying rock, nor under boggy conditions. Bracken is rarely grazed by sheep but is eaten by cattle when other herbage is scarce, and continued consumption causes poisoning. Bracken is the principal weed of hill land. Control is discussed later (p. 483).

Mountain Bog.—Land that is too wet for *Molina*, and especially stagnant bog on high plateaux, is usually dominated by cotton sedge or drawmoss (*Eriophorum vaginatum*). This provides valuable feed in early spring before other hill plants have begun to make growth. The leaf bases, which are pulled out by grazing sheep, are rich both in protein and phosphates, a circumstance that may explain the shepherd's belief that drawmoss stimulates milk production in the ewe. The commonest associate is deer sedge (*Scirpus caespitosis*).

Flush Land.—It will be readily understood that soil conditions will be markedly changed where water, having percolated through basic parent material, reaches the surface as springs. The sites of such springs, on hillsides, are marked by patches, often triangular in shape, of vivid green, the apex being at the point where the spring emerges. If the sward is examined it will usually be found to contain a considerable amount of clover, and a variety of the better grass species. The value of even a small amount of flush land—because of the high protein and mineral content of the herbage—is considerable.

IMPROVED PERMANENT GRASSLANDS

Some fields of old grass are used solely for grazing, some are mown annually for hay (but are normally grazed in the latter part of the season), while others are grazed in certain seasons and mown in others. There is thus no clear-cut division between pastures and meadows. The character of the herbage is, however, considerably influenced by the frequency of mowing.

Most old pastures contain a large number of species of more or less useful grasses, legumes, and other herbs, together with

numbers of others that can properly be regarded as weeds. Moreover, there is, of course, no sharp distinction between the poorest of the "improved" grasslands and such "semi-natural" associations as the downland fescue and the upland fescue-agrostis already described.

The botanical make-up of permanent pasture swards (*i.e.* of swards that are grazed rather than mown) is usually complex, but one or two species are often dominant. The relative proportion of the various species depends on a number of factors—the rainfall and the water-holding capacity of the soil, the elevation and exposure of the site, the lime and phosphate status of the soil, the make-up of the grazing stock (sheep, cattle, etc.), and the degree of grazing control. The constituent plants are generally grouped as grasses, legumes, and miscellaneous species or "herbs," and each group in turn is divisible into good, middling, poor, and worthless.

Among the grasses, ryegrass, cocksfoot, timothy, meadow fescue, and meadow foxtail are of first quality. Second-grade species, according to the majority view, include rough-stalked and smooth-stalked meadow grass, crested dogstail, golden and tall oat, hard fescue, and both common bent (*Agrostis tenuis*) and fiorin (*A. stolonifera*). The third group includes such as are of low productivity, nutritive quality or palatability, but which are eaten by the less fastidious animals—sweet vernal, the small fescues, Yorkshire fog, creeping soft-grass (*Holcus mollis*), downy oat, meadow barley, soft brome, and wavy-hair grass. The fourth list of species (that must be regarded as weeds even under the poorest conditions) includes tussock grass, tor grass, and erect brome.

By much the most valuable of the legumes is wild white clover. Other useful species are wild red clover, bird's-foot trefoil, and kidney vetch. Yellow suckling clover and black medick are less desirable. The only out-and-out weed in this group is rest-harrow.

Among the common herbs that are readily eaten are yarrow, rib-grass, and burnet. Among those of little value but not particularly aggressive are daisy, the hawkweeds, dandelion, and broad-leaved plantain. Troublesome weeds are the spear and field thistles, docks, the bulbous and creeping buttercups, and sheep's sorrel. Poisonous weeds include the widely spread ragwort and the very local but much more deadly autumn crocus

(*Colchicum*). The garlics, though non-poisonous, are highly objectionable in dairy pastures because their pungent taste and smell are imparted to the milk of animals that eat them.

In meadows—fields that are frequently mown—the tall-growing species such as tall oat, meadow foxtail, tall fescue, timothy, meadow vetchling, and wild red clover, and tall umbelliferous herbs, tend to dominate the more prostrate species such as ryegrass and white clover. Excessive soil moisture is reflected in colonies of rush, meadowsweet, reeds, and other water-tolerant species. Very wet places may harbour poisonous species, especially water dropwort and other umbellifers. Yellow rattle, which is parasitic on grass roots, is common in south-country meadows, especially on heavy soils.

The majority of improved permanent pastures can be conveniently classified according to the proportion, in the sward, of three species—ryegrass, bent, and wild white clover. The associations, in descending order of value, are described as ryegrass-clover, ryegrass-agrostis-clover, agrostis-ryegrass-clover, agrostis-clover, and agrostis. Thus top-grade fattening pastures, *e.g.* those of the Midlands and of Romney Marsh, are of the first class, ryegrass being dominant, wild white clover sub-dominant, and the association including smaller amounts of cocksfoot, rough-stalked meadow grass, timothy, etc., with only small amounts of bent, Yorkshire fog, and other poor-quality species. The maintenance of this association depends on a regular supply of soil moisture, a fairly high lime and phosphate status, and a system of management that combines winter rest with full summer stocking. At the other extreme, the agrostis sward is established on rather acid soil, with a low phosphate status, where over-grazing in winter is combined with under-grazing during the growing season. Such land generally carries a " mat " of dead but only slightly decayed herbage, formed from the ungrazed material under acid conditions and in the consequent absence of earthworms. Practicable measures of improvement (short of ploughing out and re-seeding) can, of course, improve the botanical composition of the poorer swards, but only to a level that depends upon the unalterable climatic and soil factors.

In some particular areas the foregoing basis of classification is not entirely appropriate. For instance, on chalky soils the small fescues take the place of agrostis, while in most of the

north *Holcus* and *Agrostis* tend to be co-dominant in the poorer swards and to be sub-dominant in the better. Indeed, under conditions of extreme acidity in northern industrial districts the poorest pastures are sometimes dominated by creeping soft grass (*Holcus mollis*).

Methods of improvement are discussed later.

Agricultural Characteristics of the Main Herbage Species.—A knowledge of the characteristics of herbage species is essential to the successful establishment and after-management of sown grasslands. Some of the qualities desired in a grass or clover are self-evident—productivity, palatability, and nutritive value. Others of importance in particular circumstances are *persistence*, *i.e.* the power to survive and to spread by vegetative methods (tillering); *aggressiveness*, *i.e.* the power to survive the competition of, or to suppress, other species; *frost-tolerance* (winter-greenness); *seasonal distribution* of production; *power of recovery* from hard grazing and treading; and *drought resistance*. *Leafiness* is important from two points of view—firstly because the leaf and leaf-base contain a smaller amount of lignified tissue than stem (and are therefore more nutritious), and secondly because a stemmy habit is often associated with high seed production and this in turn with a short life. Again, the capacity of the plant, under appropriate management, to produce a tolerable yield of viable seed is of obvious economic importance. Finally, some of the species that are potentially very valuable are ill-adapted to particular conditions—*e.g.* ryegrass to thin and poor soil under a dry climate.

A further complication arises from the fact that herbage species, like other cultivated plants, show a wide range of genetic variability so that it is possible, by continuous selection and other means, to create strains, within each species, of rather widely different characteristics—*e.g.* with varying growth habits and related responses to environmental conditions. Moreover, certain important economic characters are correlated in greater or less degree; for example, " pasture " strains not only tiller or produce runners freely, and are typically of rather low, spreading habit, but are also, in general, late in starting spring growth. Conversely, " hay " strains are not only tall and upright in habit, but are less inclined to tiller and tend to be early. Differences between strains of the same species may be greater than those between average specimens of different species.

Thus ryegrass is early and timothy is late, but an extreme hay type of timothy may be earlier than an extreme pasture type of ryegrass.

Another general point in relation to strains is of practical importance. All the agricultural species are cross-fertilizing, the grasses being wind-pollinated and the clovers insect-pollinated. Many individual plants are self-sterile, and those that are self-fertile, when self-fertilized, give a high proportion of worthless progeny. The continued inter-crossing that occurs in the field maintains a greater or lesser range of variability—apart altogether from the possibility of pollination from an outside source, *e.g.* of plants in an old pasture by pollen from an adjacent ley.

As would be expected, seed harvested from an old pasture yields a large majority of leafy and persistent types. But if a stock obtained from such a source is repeatedly grown for seed, and especially if seed is taken in the first year after sowing (which is convenient in practice), the forms that will be inadvertently selected will be those that run to seed freely and bear seed abundantly; and these are undesirable for many purposes. Many early attempts to propagate indigenous types of ryegrass broke down because of failure to recognize this difficulty. The desirable characters of a strain can be maintained only by returning frequently to a stock of "mother" plants—either to an old pasture or to a "pedigree" stock that is subjected to constant selection. In either case, precautions must be taken against contamination by pollen from outside sources.

The Ryegrasses.—As already said, perennial ryegrass is native to Britain, is widely distributed in the better old pastures, and is dominant in the best of these. But the seed which first became available in commercial quantities was that of a type which (along with red clover, Dutch white clover, and trefoil) had long been cultivated from seed in Flanders. The other "artificial grasses" of the old writers were lucerne and sainfoin. Italian ryegrass was introduced in 1831 from Northern Italy, where again it had been long cultivated. Seed of indigenous types of perennial ryegrass, from old pastures, has been used from time to time, but increasingly in the last twenty years. Also, during this last period, pedigree strains have steadily increased in popularity. The most recent introduction is New Zealand "short-rotation" ryegrass (H. 1), which derives from a cross between selected forms of the Italian and perennial types.

Italian Ryegrass is easily distinguishable from typical plants of perennial by its more tufted and upright habit, its broader leaves, rather lighter green colour, longer spike with spikelets more widely spaced, and by the presence of an awn on the seed. It is, however, regarded as a sub-species. In general, the plant behaves as a biennial, but when grown under favourable conditions and when closely grazed it may survive longer. Its presence in second- and third-year swards is, however, often to be explained by self-sowing.

Under suitable conditions Italian ryegrass is exceedingly productive. Its requirements in the matter of soil nutrients and moisture are, however, high. It succeeds on relatively poor soils in the wet uplands provided that ample amounts of fertilizers, and particularly of nitrogen, are applied, but it is of less value on thin and light land in the drier areas. It is the principal grass for one-year leys, and is valuable as a catch crop, sown either by itself—*e.g.* after early potatoes—or under-sown in corn with the object of producing autumn and winter grazing. It is frequently used as a " nurse " (in place of a cereal crop) when sowing down land to long leys, but in this case it is essential, if the perennial grasses and clovers are not to be crowded out, that the new sward be kept closely grazed from the outset. Again, it is often included in mixtures for two or more years' ley in order to increase the yield of herbage during the first year. If the field is to be grazed in the first year this may properly be done, but if hay is taken in the first year the slower-developing species may be overtopped and suppressed. Under average conditions it combines well with broad (early flowering) red clover in one-year mixtures, reaching the hay stage at about the same time; but if the land is very rich, or if a large dressing of nitrogen is applied, it tends to suppress this or any other clover.

Italian ryegrass grows late in autumn, makes growth during short spells of mild weather in winter, and produces grazable herbage, or material suitable for drying, earlier than any other grass. When heavily fertilized and irrigated, or when treated with liquid manure, it may be expected to give four cuts in a normal season, with a total yield of 4 or 5 tons per acre of dry matter which is of high nutritive value. The seed is relatively large but light, running about 225,000 per lb. Under good seed-bed conditions 8 or 10 lb. per acre will produce a sufficient stand for a crop of hay. Where, however, the objective is the

rapid formation of a dense turf—*e.g.* where the improvement of soil structure is the main consideration—seedings of 50 lb. per acre or more are sometimes used. Four to 6 lb. is a suitable amount when the grass is being used as a "nurse." As a "pioneer" crop, in the reclamation of derelict grassland, it may be used alone or may be combined with rape, or with rape and hardy green turnips. Commercial seed is mainly produced in Northern Ireland and France.

An annual variety, known as Westernwolths grass, is obtainable, but seems to have no particular advantage, even for catch cropping, over the ordinary type. A pedigree strain, S. 22, has recently (1951) been released by the Welsh Plant Breeding Station; this has been selected mainly for leafiness, but appears also to be more persistent than the Irish or French "commercial" forms.

New Zealand short-rotation ryegrass (H. 1) is another leafy form, combining the earliness and high productivity of its Italian parent with a good deal of the powers of survival of New Zealand perennial. Under good conditions in the south and west of England it continues in full production for at least three, and often for four, harvest years. It may thus, with advantage, replace perennial ryegrass in short leys, whether for grazing or to produce material for drying or ensilage. The evidence from other parts of the country, at the time of writing, was hardly sufficient to justify a general statement.

Perennial ryegrass exists in a wide variety of forms which, however, have many characteristics in common. It is, among all the better grasses, the easiest to establish from seed, and the seedlings develop rapidly. This is not an unmixed advantage, since the grass competes so strongly in the seedling stage with species of slower development, such as timothy and meadow fescue, that these may be almost completely suppressed. It is more or less evergreen and makes some growth (though less than Italian ryegrass) in mild periods during winter when many other species remain completely dormant. It withstands (and, indeed, benefits from) close grazing during summer, but it is greatly weakened by frequent severe grazing in winter and early spring—so much so that it may, in the succeeding summer, be dominated by other plants—*e.g.* white clover or agrostis—that lie dormant over winter and commence spring growth relatively late. Conversely, a pasture that is ungrazed in winter and early

spring will tend to become ryegrass-dominant. Ryegrass grows vigorously in spring and early summer, and again from September until the onset of winter, but it makes relatively little growth during July and August even if soil moisture is abundant. In the drier parts of the country this summer dormancy is especially marked. Given well-controlled grazing and suitable manuring, ryegrass will maintain a balanced partnership with white clover and palatability is sustained at a high level throughout the season. Ryegrass demands, for full productivity, a higher level of nutrient supply and a higher lime status than certain other good species; moreover, in dry climates, or on soils that are liable to dry out, species with deeper-ranging root systems are more productive.

The common *commercial* types, of which the most important is grown for seed in Northern Ireland, are early both in commencing spring growth and in throwing up flower heads. They have few barren (non-flowering) shoots, and are only weakly tillering. They have a relatively high proportion of stem to leaf and a marked tendency to summer dormancy. Since the seed crops are heavy and easily saved, the seed is ordinarily cheap. Grown for hay under conditions of good or high fertility, commercial perennial is liable to lodge. Persistency varies with conditions: on poor thin soils and in dry areas, especially if it is allowed to reach or pass the hay stage or is over-grazed in winter, it may virtually disappear by the mid-summer of the second harvest year. At the other extreme—on fertile soils, under a moist climate, and with regular grazing—many plants may survive a third or fourth season. Under average conditions its main use is for two-year leys.

Other "commercial" or "semi-commercial" types are of only local importance. The best known is Devon Eaver, which is remarkably winter green and very early.

Seed of *indigenous ryegrass* is harvested (usually along with wild white clover) either from old pastures or from leys that have been established by sowings from such old pastures. In the latter case the seed is known as "once-grown." The chief centre of production is Kent, and a certification scheme is in operation whereby the authenticity of the produce is guaranteed. There is some variation in type according to the source—Romney Marsh, the Weald, or the Upland areas—but in general the plants are about mid-way in earliness, tillering capacity, and in the proportion of barren tillers, between the extreme forms—

" commercial " on the one hand and the pedigree pasture types on the other. Kentish ryegrass seems to have some degree of adaptation to low-rainfall conditions.

The pedigree strains have been selected for leafiness and persistence and to meet the varying conditions and requirements. The best known are Aberystwyth S. 23, S. 24, and S. 101, but certain seed houses offer others.

S. 23 is the most widely used of the three. The foundation stock was selected entirely from very old pastures, mainly in the Midlands, Kent, and Lincolnshire, but also from Holland and Wales. It is late-flowering—about three weeks later than typical " commercial " forms—and has a rather spreading growth habit. It tillers strongly, has many non-flowering shoots, and the growth is dense and leafy. Spring growth is slow, but summer dormancy is much less marked than in the commercial forms, while autumn production is very good. The plants remain green during winter, with rather active growth in mild periods. Under reasonably good management the density of its sward prevents the intrusion of bent and other inferior plants, and its persistence under grazing conditions is very striking. As would be expected, seed production is low by comparison with that of other strains. Though it is the best form of ryegrass for long leys under poor conditions (at least under high rainfall) it responds well to liberal treatment, especially with nitrogen. In long leys it blends well with the smaller types of white clover (wild white and S. 184). For leys of intermediate length, S. 100 or New Zealand white clover is generally chosen as the companion plant, though in this case some care is necessary to avoid the dominance of the clover.

S. 24 represents the other extreme form. The aim in selection has been to combine the good qualities of the Irish and Ayrshire " commercial " forms—their earliness and capacity to produce a large bulk of hay—with quicker recovery after mowing, a less-marked propensity for the aftermath to run to seed, a more leafy habit, and some improvement in persistency—though much less than in S. 23. In spring growth it is rather earlier than the commercial type, but it comes into flower, if anything, a little later. It produces a high yield of seed, which is consequently fairly cheap. It may thus be used, with advantage, to replace commercial ryegrass in leys for two or three years, especially where hay is to be taken in one or more.

S. 101 is also derived from plants found in old pastures, but

in the Midlands and Kent only. It flowers only slightly earlier than S. 23, but the habit of growth is less spreading, with longer and often broader leaf blades. It produces a less dense sward than S. 23 and is less persistent under poor conditions and under close and continuous grazing. On the other hand, it has a more erect habit, and yields a good cut of very leafy hay.

Perennial ryegrass seed is similar in weight to that of Italian (about 250,000 per lb.). Seed rates vary rather widely. S. 23 quickly forms a close sward by tillering; when sown without a nurse and under good seed-bed conditions, 8 or 10 lb. per acre, with perhaps 3 or 4 of white clover, will suffice. The cost of seed per acre is therefore not excessive. At the other extreme, with commercial types intended to constitute about two-thirds of the total for a two-year ley, sown in corn under average seed-bed conditions, the seed rate is generally of the order of 20 lb.

Cocksfoot is second in importance only to ryegrass. It readily establishes from seed even in competition with ryegrass; it reaches full productivity almost as soon as perennial ryegrass and outyields the latter on the lighter and shallower sorts of soil and under low-rainfall conditions. It is, however, less easy to manage successfully, since it tends, when under-grazed, to become coarse and tufted. It comes into full growth, in spring, at about the same time as ryegrass, with a rather narrower range between the early and late types. There is, however, a marked contrast between the two species in the seasonality of production. Some types of cocksfoot are moderately winter green, others dying back (" winter burning ") after the first considerable frost. In any case, there is little or no winter growth. On the other hand, no pasture plant except lucerne is so productive during the late summer, when ryegrass, as said above, is often dormant. The drought-resistance of cocksfoot is partly at least to be explained by the deep and strong root-system which it develops. There is also some evidence that, probably again by reason of its strong root development, the plant is specially efficient in building up a desirable soil structure. It should, however, be noted that the full development of roots depends upon leniency in grazing at certain times of the year. If the plant is kept closely cropped throughout the early part of the season its root-system will be weakened and its drought-resisting powers accordingly reduced. Moreover, cocksfoot is capable of laying up, in August-September, a large reserve of food material in its roots

and leaf bases, and the vigour of its spring growth depends on the amount of these reserves. The maximum value is thus to be obtained from a cocksfoot-dominant ley only by a carefully planned system of utilization. One such plan is to take the first growth for grazing and to lay up the field in April for a crop of silage, which is taken about the time that the flower-heads appear, *i.e.* ordinarily at the end of May; the aftermath is grazed from perhaps mid-July till late August, and the subsequent growth is allowed to stand over for consumption by out-wintering cattle. It will thus appear that a ryegrass-dominant and a cocksfoot-dominant ley can be mutually complementary, providing good grazing over a long and continuous period and also yielding a considerable amount of herbage for conservation.

Many different views are held in regard to the palatability of cocksfoot. There is no doubt that the first spring growth, and also the young aftermath, is greedily eaten by all classes of stock. But the more mature growth tends to be neglected by animals that have free range and opportunity for choice. This difficulty can be overcome by having a group of " followers "—store stock, dry cows, etc.—to clean up after a herd of dairy cows or fattening cattle or a flock of ewes and lambs.

Among the " commercial " types of cocksfoot, American is unsuited to British conditions, being early but coarse and stemmy. Danish is widely used (more especially in the north of England and in Scotland) because it is there the most reliable provider of the early keep that is so important for nursing ewes. But it is troublesome to control in the latter part of the season, with a pronounced tendency to form tufts.

The pedigree strains are exemplified by the well-known Aberystwyth series.

S. 143 was developed from indigenous plants of an extremely leafy type. It forms broad cushions rather than tufts. It may be regarded as the fellow of S. 23 ryegrass, but departs even further from the average of its species. The leaves are broad and very palatable and there is a profusion of tillers. It is productive and persistent on poor soil and under hard grazing, but comparatively late. It is a poor seed-bearer when grown in a sward, but yields well when grown in rows with appropriate fertilizer treatment. It blends very well with the more vigorous types of white clover. S. 37 is tall and erect, but more leafy than Danish and almost as early. Under difficult conditions it is less persistent than the

other pedigree strains, but is also less prone to get out of hand in a mixed sward. S. 26 is the intermediate form, making a persistent sward under grazing conditions but yielding also good crops of leafy hay. It tillers more profusely than S. 37 and much more so than Danish. Scotia (Scottish Plant Breeding Station) is similar in type to S. 37 and may be more suitable to northern districts.

Cocksfoot seed is about half the size of ryegrass (about 450,000 per lb.) and, since establishment is relatively good, 6 to 10 lb. per acre will usually suffice to form a cocksfoot-dominant sward. A very small amount in a complex seeds mixture is apt to result in very tufted plants.

Timothy.—It has long been agreed that timothy is a valuable grass for hay, but its place in modern pasture-making is less clear. The hay types thrive best on heavy or peaty land, and a stand, even of the commercial Scotch type, may remain productive and relatively free from intruders for five, seven, or even ten years. It has long been the custom in the Scottish " carses " (alluvial clays), and also on the clay-land dairy farms of Ayrshire, to grow the plant in pure culture, with a little ryegrass and red clover to increase the yield in the first season. With heavy dressings of fertilizer (and especially of nitrogen), yields of 4 tons per acre, in a single cut, are not unusual. Attempts to repeat these results in the clay lands in warmer and drier areas have never fully succeeded.

A small amount of timothy is included in standard mixtures for three- or four-year leys (Cockle Park and Craibstone mixtures), but in competition with ryegrass and cocksfoot establishment is often poor. Moreover, the seasonality of production is unlike that of ryegrass or cocksfoot, since spring growth starts late and the grass reaches the hay stage about three weeks later than ryegrass. When mown for hay at the normal stage the aftermath is very small, being usually left as wintering for sheep. The most successful results, in pasture leys, have been secured by sowing it in combination with meadow fescue and the larger forms of white clover.

What has been said does not apply to the S. 50 strain, which may almost be regarded as a separate species. It is, in fact, genetically distinct, being a diploid form which does not intercross with the other (tetraploid) strains. The foundation stock was raised from " rootings " (portions of the creeping stolon)

procured from some of the finest old pastures. S. 50 has a very spreading habit, forming very low grassy cushions which carry few and short-flowering stems ending in slender heads. After flowering there is a large production of barren tillers, which trail over the ground and often branch profusely. When trodden into the ground these root at the nodes. This strain, as will be understood, is a poor seed-bearer, and the seed is difficult to harvest. It makes a compact lawn-like sward which withstands invasion by inferior grasses and other weeds. It may therefore have a special value in areas where deterioration of sown swards is specially difficult to prevent.

The most widely used of the "ordinary" timothies are Scotch and Aberystwyth S. 48. The latter is much later-flowering and more freely tillering, more leafy, and also more winter-green. It is, moreover, highly resistant to rust, which is a common and serious disease. S. 48 yields heavy crops of hay and yet persists under heavy grazing, except indeed where the soil is very light or very low in organic matter. S. 51, which has a characteristic light-green colour, is also rust-resistant. It is essentially a hay type but produces a much better aftermath than the Scotch and other commercial forms. It persists well unless it is closely grazed by sheep.

Timothy seed is very small—about a million to the pound—so that, despite rather poor powers of establishment, seed rates are relatively low. Under favourable seed-bed conditions 10 lb. per acre, with a normal amount of clover, will produce a full stand.

Meadow Fescue has long been recognized as a productive, persistent, and nutritious grass, and was almost invariably included in the highly complex seeds mixtures that were formerly recommended for long-duration leys or permanent pasture. In fact, its seedlings are so completely suppressed by those of rye-grass and cocksfoot that its inclusion under such conditions was quite unavailing. Meadow fescue can, however, flourish in combination with timothy or lucerne or both, or with timothy and white clover. In general, meadow fescue, by contrast with cocksfoot, is most useful on moderately moist and fertile soils. The best of the commercial types is Danish, which is early but not so leafy as might be wished. S. 53 is a late, leafy, free-tillering and persistent type, but taller than the extreme pasture strains such as S. 23 ryegrass, and hence more useful for hay. S. 215 is tall, erect, a few days earlier than Danish, and yields both a

1. Crested Dogstail 2. Italian Rye-grass

Sutton

3. Meadow Fescue 4. Meadow Foxtail

5. Perennial Rye-grass 6. Cocksfoot

Sutton

7. Rough-stalked Meadow Grass 8. Smooth-stalked Meadow Grass

heavy crop of hay and a lush and leafy aftermath. The seed of meadow fescue is similar in size and shape to that of perennial ryegrass.

A considerable number of other grasses are occasionally sown under special circumstances, or were under investigation at the time of writing. **Tall Fescue** is a strikingly tall and broad-leaved sub-species of meadow fescue, is deeper-rooted than the latter, and grows more vigorously on poor, light land. It is generally regarded as too coarse and unpalatable to be included in grazing swards, but it yields a bulky cut early in the year and may have possibilities for ensilage or drying. **Tall Oat Grass** is commonly grown for hay in France. It is very productive under dry and hot conditions but cannot survive hard grazing or treading. It seems to have no particular place under British conditions. **Meadow Foxtail** is indigenous in British grasslands, is extremely early, is quite productive under moist conditions, and grows well under moderate shade. Unfortunately it is very difficult to establish from seed and comes very slowly into full production. Moreover, seed crops suffer severely from attacks of the foxtail midge, so that yields are often very poor. **Smooth Broome** (*Bromus inermis*) is very widely grown in Central Europe and in North America, especially as a companion plant to lucerne. It is highly drought-resistant but seems to require a hotter climate than that of any part of this country. The possibilities of **Canary Grass** and **Reed Canary Grass**, and of a hybrid between the two, have been under trial, but no definite recommendations about their use could be made at the time of writing.

Among the so-called " Bottom Grasses " the most useful is **Rough-stalked Meadow** which thrives on heavy moist soils, and, indeed, reproduces so freely that it survives in arable crops to an extent that makes it a weed. In former times, when only " commercial " types of ryegrass and cocksfoot were available, it was often included in mixtures for the heavier sorts of land with the aim of maintaining a close sward. But with the advent of S. 23 ryegrass and S. 143 cocksfoot the case for its use is a doubtful one. **Smooth-stalked Meadow Grass** (the American Kentucky Blue Grass) is drought-resistant but markedly summer-dormant. It is strongly creeping (stoloniferous) and more prone than rough-stalked to become an arable-land weed. **Crested Dogstail** is widely distributed in old pastures under a variety

of conditions. It is winter-green, but produces only a small amount of keep, and it seeds very freely because its wiry flower stalks are neglected by grazing stock. It may be included in long leys on poor land where the livestock is mainly sheep. **Golden Oat Grass** persists well on very dry sites and is perhaps worth sowing on land that " burns " in summer. **Agrostis,** as said earlier, is dominant in many of our third-rate pastures. It thrives on acid soils and under other conditions which lead to the rapid decline of the better grasses. The possibility of creating improved strains is being examined.

CLOVERS

Red Clover (*Trifolium pratense*).—Wild or indigenous red clover is found growing in some of our old pastures and hedge-sides; it is a rather woody perennial; its seed is on the market, but it is distinctly less valuable than wild white clover.

Broad red clover, which is probably indigenous to southern Europe, has an erect habit of growth and relatively large leaves. It is a biennial that establishes itself quickly and is comparatively early. It may be used as a catch-crop and for one-year seeds. Because of its short life, however, and because its early and rapid growth has a depressing effect on wild white clover, it is unsuitable as a constituent of mixtures for long-duration swards. It is susceptible to " clover-sickness," which is usually due to the fungus *Sclerotinia trifoliorum*, but sometimes to eelworm. Most seed is English grown, but some is also imported from Sweden, Canada, U.S.A., Chile, New Zealand, and a number of other countries. Stocks from these various regions show considerable differences in their characteristics, and those from dry, warm climates—*e.g.* Lombardy—often fail to survive British winters. Aberystwyth S. 151 is an early, good-cropping strain that persists better than the commercial English type in the second year. There are various local strains—*e.g.* Dorset Marl—which vary in type and in adaptability to local conditions.

Late-flowering red clover, sometimes known as single-cut cow-grass, differs from the broad red variety in having narrower and more pointed leaves, being more spreading in habit of growth, tillering better, and lasting into the second or third year of the grassland; it is relatively slow to reach its full productiveness and is late in starting spring growth; it produces very little

aftermath; it is rather less susceptible to clover-sickness than broad red. Late-flowering red clover is an important plant in the first two years of a sward, and, when sown with a species such as perennial ryegrass, contributes largely to the yield of hay and greatly increases the yield of dry matter per acre. It is often included in mixtures that are sown down for more than one year and intended for hay in the first season. In districts where long-duration swards are hard to establish it may be omitted from the seed mixture, for although it is not as hard on wild white clover and the slow-growing grasses as is the broad red variety, it nevertheless delays to some extent the establishment of these species. Strains and types may be divided into medium, late, and very late. Among the former are Essex, Norfolk, Cotswold, and Vale of Clwyd; among the extra late are Montgomery, Cornish Marl, and S. 123. The latter group are the more persistent and the more reliable under poor conditions. Some of the strains are "certified" by the local seed growers' associations.

Red clover grows best on well-drained clay loams in a high state of fertility and well supplied with lime. Complete failure is likely if the soil is more acid than *p*H 5·3. The late-flowering sorts are better than the broad-leaved strains for withstanding poor conditions, but even they will fail on sour and water-logged soil. Red clover has a deep root-system and does not often suffer from drought. Its agricultural value lies in its nitrogenous nature and its power to produce a large bulk of nutritious foliage which may be grazed, soiled, made into hay, or utilized for green manuring. On the other hand, owing to its susceptibility to disease, its limited adaptability to soil conditions, and perhaps to the use of unsatisfactory strains, red clover is a somewhat uncertain cropper. It should be grazed down after the harvest of the nurse-crop to prevent its flowering and thus prolong its life and also as a measure of control against the clover rot *Sclerotinia*.

In the south-east of England red clover is often sown alone, but elsewhere it is more usual to sow it, at the rate of 2 to 10 lb. per acre, in mixture with grass seeds. The seed runs about 230,000 per lb., about the same as that of ryegrass. The usual amount of Late-flowering Red in general-purpose leys that are to be mown in the first year is 2 lb. Seed rates for a pure stand of Broad Red are usually between 12 and 18 lb.

Alsike Clover (*Trifolium hybridum*).—This clover was

introduced from the Continent in 1834, and takes its name from a parish in Sweden. Alsike is not a true perennial, but is more lasting than most strains of red clover, and on good soil may continue to grow for three years. Unlike white clover, it has an upright habit of growth and is therefore more suitable for hay than for pasture; its flowers are intermediate in appearance between those of red and white clover, and this has probably led to the erroneous belief that it is a cross between these sorts. It commences growth later and does not produce so much aftermath as broad red. Alsike does best on heavy, damp soils, and since it is fairly resistant to clover-sickness, and will grow under conditions that inhibit the development of the red variety, it is frequently included in mixtures to ensure the presence of a plant should the red clover fail; indeed, it should always be included where the growth of red clover is uncertain, as its "take," except on sour land, is almost invariably good. It is inferior to red clover, however, in producing bulk, and should the red sort develop strongly the alsike is choked down and its yield is small. In mixtures for long leys the more vigorous strains of white clover are much more useful than alsike.

The seed of alsike, which is largely imported from Canada, is small (about 700,000 per lb.), and when sown with other clovers and grasses, 1 or 1½ lb. per acre should suffice.

White Clover (*Trifolium repens*).—Dutch white clover is not a true perennial, though under good soil and climatic conditions it is rather more lasting than alsike. The variety is procumbent in habit, but, unlike wild white clover, its trailing stems do not root freely at the nodes; it is well suited to form the bottom herbage in one-year leys that are intended for pasture, and especially for sheep grazing. As it produces very little top foliage it is almost useless for mowing, but it is highly nutritious. It grows on all types of soil and, being deep rooted, is resistant to drought; it will not grow in the shade. There are parts of the country where it is too short-lived for any except one-year leys, but in other places it may be included to the extent of about 1 or 2 lb. per acre in mixtures for two years.

New Zealand certified white clover is intermediate in character between Dutch white and wild white. Aberystwyth S. 100 is a highly productive and early strain of somewhat similar type, which in many parts of the country is the standard for leys of intermediate length. Kersey white, which may have originated

from the New Zealand type, is a third member of this group. All three forms spread freely by runners. Under good conditions they are more productive than wild white, but are somewhat less persistent under upland conditions and on poor land. Some care is necessary to prevent their dominating the lower growing grasses such as S. 23 ryegrass and S. 50 timothy.

Ladino white clover, which is of Italian origin and is widely grown in North America, was under trial in this country at the time of writing. It seems to be unable to tolerate the close grazing which is usual in Britain.

Wild white clover is fairly easily distinguished from the Dutch variety in appearance, being smaller, later in flowering, more actively creeping, and rooting freely at the nodes. As it is almost the only useful perennial legume found in many of our pastures it has a great significance from the point of view of nitrogen fixation and the improvement of the soil. It is an indigenous plant and tends to increase where conditions are favourable; it is much more resistant to soil acidity than is red clover and it withstands drought. Wild white clover commences growth somewhat late in the season. Hence, if a pasture is left ungrazed during the spring period (April-May) the clover will tend to be suppressed by early grasses such as cocksfoot and ryegrass. Close grazing at this time encourages the clover at the expense of the grasses. Excessive growth of clover is undesirable because a too clovery pasture tends to scour stock and probably to increase the susceptibility of cattle to bloat. The causes of bloat are, however, far from being fully understood. Wild white, moreover, produces very little keep in winter and spring.

The seed of wild white clover is harvested from old pastures,[1] and the various types show considerable differences owing to the varying conditions to which each has become acclimatized. Thus there are more or less distinct types from such places as the Weald, Romney Marsh, Suffolk, Hereford, and the Cotswolds. There is also an Aberystwyth pedigree wild white, known as S. 184, which is much more uniform in size and vigour than the produce of seed saved from old pastures. The seed of wild white clover is rather costly. Some of the seeds, and sometimes a large

[1] There is a scheme whereby fields are approved by a County Committee and by the Ministry of Agriculture, and the produce therefrom is officially "certified." This scheme must not be confused with that for red clover seed, which is certified by Growers' Associations.

proportion, are hard-coated, and may lie dormant in the soil for as long as a year before germinating. " Once-grown " wild white clover seed is got from a cultivated crop produced by sowing seed from a certified field. The effect of such cultivation is to increase the proportion of free-flowering and short-lived plants. " Twice-grown " seed gives a range of types quite markedly different from the original (see p. 455).

The seed of wild white clover runs about 900,000 per lb. and that of Dutch white about 750,000. The other types are intermediate. Usual amounts in mixtures are ½ to 2 lb. of wild white or S. 184, and 1 to 4 lb. of the larger types.

Trefoil (*Medicago lupulina*).—This is a legume which has no value for permanent pastures but is useful for short leys on poor, shallow, and sandy soils where the better clovers will not grow. It is chiefly used for one-year mixtures, as after fifteen or sixteen months it dies out and allows weeds to develop. It is sown as a substitute for red clover on land that is clover-sick. It is very sensitive to soil acidity.

The seed is relatively large (300,000 per lb.), and normal seed rates for pure stands are around 20 lb. per acre.

Kidney Vetch (*Anthyllis vulneraria*).—This is a legume which thrives on poor, light, sandy, and chalky soils; it is extremely hardy and resists both cold and drought. It is not truly permanent but may last several seasons, and where red clover will not grow it can be included in mixtures to the extent of 2 or 3 lb. per acre.

Lucerne (see p. 408) is frequently grown as a pure stand but is also being increasingly used as a component of " special purpose " leys (see p. 461).

Birdsfoot Trefoil (*Lotus*) is being increasingly grown in countries where white clover is insufficiently frost-hardy or is otherwise difficult to grow. It is doubtful whether the plant has any place in Britain.

HERBAGE SEED PRODUCTION

The production of grass and clover seed is, in many cases, a highly specialized enterprise, and the subject can here be dealt with only in general terms.

The " commercial " strains of grasses, which seed freely and are tall enough to be harvested by the binder, are ordinarily

grown as pure stands, or with a little clover, on clean ground, and are commonly sown under corn. The grass crop is cut, bound, and stooked when the seed is ripe, but if possible before any seeds have shed. Careful handling is necessary during carting, stacking, and subsequent threshing, otherwise much seed will be lost. An ordinary threshing machine can be set to deal with grass-seed crops. If the threshed seed is not thoroughly dry it is either put through a drier or, more commonly, is spread thinly on a barn floor and turned over as often as may be necessary to avoid the slightest heating. The seed is generally sold, as grown, to a wholesale seed merchant who is provided with the rather elaborate machinery required for cleaning.

Red clover seed is also commonly produced from pure stands, the broad red after an early cut of hay and the late-flowering types from the first growth—except that the plants may be lightly grazed in early spring. The clovers depend upon insects—and red clover mainly upon humble-bees—for pollination, so that the yield is very dependent upon fine weather during the flowering period. In wet seasons the intention of taking seed has often to be abandoned. The time for cutting is when the flower heads have turned brown, and when hard and well-coloured seeds can be rubbed out of them. A well-ripened crop, given a spell of fine dry weather, can be combine-harvested direct; otherwise it may be cut, left in swath for a day or two, and dealt with by a pick-up combine-harvester. Alternatively, the ripe crop may be mown and carted or swept to stack to be threshed at any convenient time. Since the price of clover seed fluctuates widely from year to year (because of great variation in yield), crops are often held over, in stack, for a year or more. A special machine (a clover "huller") is necessary for threshing. The large-scale grower may have his own, but more usually the work is done on contract.

Seed of indigenous ryegrass and wild white clover, and also pedigree strains of these species, are generally saved from ryegrass-clover leys. In the common case, where the primary object is a maximum yield of white clover, the ley is intensively and continuously grazed with sheep until the time—some date in May—when the clover commences active growth. By this time the ryegrass will have been so weakened that, when the sheep are removed, the sward becomes clover-dominant. When the bulk of the clover seed is ripe the growth is mown, sun-dried, and stacked for later threshing. If the crop is very short it may be

gathered on a sheet attached to the cutter bar and raked off to form small wads. The ryegrass seed, which in some seasons will be a small proportion of the whole, is easily separable from the clover. It will readily be understood that different treatment —the unstocking of the field from autumn onwards and the application of a spring dressing of nitrogen—will reverse the proportion of the two species in the mixture.

The pedigree strains of the taller grasses are commonly sown in rather widely spaced rows (about 2 ft. apart) on well-cleaned ground, and usually without a nurse crop. In order to avoid contamination by wind-blown pollen—*e.g.* from adjoining pastures or meadows—the site must be carefully chosen, and hedgerows must be cleared of any plants that might cross-pollinate with the crop. The seed sown should be derived from a certified strain, preferably " mother " seed. Seed rates are small—ordinarily 4 or 5 lb. per acre. Sowing in rows, combined with heavy applications of fertilizer (especially nitrogen), changes the natural habit of growth and induces a high production of flowering heads. The rows are grazed only after autumn growth has ceased so as to enable the plants to store abundant food reserves. Seed is normally taken for two successive years—the second and third after sowing—but occasionally for three or even four. The crop may either be cut and bound or combine-harvested.

Seed yields reach about 1 cwt. per acre in the case of wild white clover to 4 or 5 cwt. of cocksfoot and perhaps 6 or 7 cwt. of ryegrass and timothy.

THE PURCHASE OF HERBAGE SEEDS

Vendors of agricultural seeds are required to declare the purity and germination capacity of what they sell, and normally guarantee the authenticity of the stock—*e.g.* certified once-grown wild white clover, or certified S. 143 cocksfoot. Certain weed seeds are very difficult to remove from those of particular grasses or clovers—*e.g.* slender foxtail from cocksfoot—and certificates may be refused for crops that are seriously infested by such weeds. The substitution or adulteration of samples sold as home-grown may often be detected by the presence of seeds of weeds that do not grow in this country. Special training is required for the certification of growing crops and for the examination of seed samples. In the case of clovers the percentage of " hard " seeds,

as well as the percentage germination, is recorded. Where hard seeds are numerous the bulk may be subjected to an abrasive process carried out in an emery-lined revolving drum.

SEEDS MIXTURES

From the species and strains that have been described it is possible to make up a vast number of different combinations, and, indeed, a great variety of mixtures have been—and still are—recommended by different authorities for different purposes. The considerations which should be kept in mind in compounding the mixtures are as follows :—

1. The intended duration of the sward. It is generally sufficient to distinguish between swards for one year, two years, and those for three years or more.

2. The intended use—*i.e.* hay, ensilage, artificial drying, pasture, or any combination of these—for example, one year's hay and two years' grazing.

3. The soil and climatic conditions, more particularly the average soil-moisture supply during the mid-summer period.

4. In the case of swards for grazing, the predominant type of stock—dairy, store or fattening cattle, or sheep—for which provision is to be made.

5. The season of the year for which the sward is intended to provide; for example, two fields of pasture may be intended to be complementary—the one to provide spring and autumn grazing and the other to yield a silage cut, to cover the summer gap, and to provide wintering.

6. In the case of a ley, the degree of importance which the farmer attaches to the build-up of soil structure. This varies according to the soil type, and the particular crops that he intends to grow during the two or three years after the ley is broken up.

One-year Mixtures.—Italian ryegrass and broad red clover—one or the other or the two in combination—provide the most productive one-year swards. On the poorer and lighter soils, and particularly on the chalk, pure clover is generally preferred since it is the better preparation for the wheat that ordinarily follows. Moreover, under a fairly wide variety of conditions, ryegrass is apt to be attacked by the frit fly, whose larvæ migrate to the wheat seedlings in autumn and may do serious damage. At the other extreme, on good land that is in high condition,

and especially if nitrogen is to be liberally applied, the ryegrass is liable to smother the clover, so that there is little to be gained by including the latter. On known clover-sick land the highly susceptible broad red clover must be replaced by more resistant legumes; the usual choice is a combination of alsike and trefoil. Where there is doubt on the score of clover sickness all three legumes may be included. The one-year ley is unusual in the colder upland areas; where used, it may be well to substitute late-flowering red clover for broad red. Although less productive in its first year, and suffering more in a hay crop from the competition of the ryegrass, its establishment is more certain.

Since there is no problem of the suppression of longer-lived and slower-establishing components in the sward, and since the seed of all the species mentioned is cheap, rather high seed rates are customary. The following prescriptions, in pounds per acre, are given as examples :—

	I	II	III	IV
Italian ryegrass	30	15	15	...
Broad red clover	...	8	4	16
Alsike clover	...	...	2	...
Trefoil	...	...	2	...
	30	23	23	16

For catch cropping Italian ryegrass is, of course, outstandingly the best choice among the grasses. It may be used in conjunction with either trefoil or rape. Trefoil may also be grown alone, but it must be remembered that it demands a high lime status. The undersowing of corn crops with Italian ryegrass or trefoil, or with a combination of the two, not only produces useful autumn grazing—except in dry seasons—but helps to control "take-all" (see under Wheat).

Two-year Mixtures.—The choice of grasses for two-year leys is generally confined to Italian and perennial ryegrass (or short-rotation ryegrass alone) and cocksfoot. Timothy has sometimes been recommended under high moisture conditions, but its seedlings tend to be suppressed in the presence of a thick stand of ryegrass. The clovers worth consideration are broad and late-flowering red, alsike, and the stronger-growing types of white—New Zealand and S. 100.

The choice in a particular case requires a good deal of consideration. If a full crop of hay is to be taken in the first year,

the early and vigorous Italian ryegrass and broad red clover will tend to suppress the other components of the sward with serious detriment to production in the second year. Moreover, they reach the hay stage earlier than perennial ryegrass or late-flowering red clover. On the other hand, they are the most useful species in the aftermath of the first year. If, however, the sward is to be grazed throughout the first season, or if, in the first year, the field is to be grazed with sheep before being laid up for hay (which is permissible in the cooler and moister areas), or again, if the first cut is to be taken for silage, the balance of argument is in favour of their inclusion. With respect to the other clovers, late-flowering red should generally be included, and a small amount of alsike may be added. Under good conditions Dutch white clover may be expected to survive throughout the second harvest year, but under poorer conditions New Zealand or S. 100 is to be preferred. The following examples illustrate these points :—

	I Good Conditions. Grazing only or Silage and Grazing	II Poor Conditions. Hay in First Year
Perennial ryegrass . .	12 lb.	16 lb.
Italian ryegrass . .	7 ,,	...
Cocksfoot . . .	5 ,,	7 ,,
Broad red . . .	2 ,,	...
Late-flowering red . .	2 ,,	3 ,,
Alsike	...	1 ,,
Dutch white . . .	1 ,,	...
S. 100 white . . .	...	1 ,,
	29 lb.	28 lb.

Long Ley and Permanent Mixtures.—It was early recognized that the "artificial grasses" were relatively short-lived under ordinary systems of utilization. In some cases they were sown alone for permanent pasture in the expectation that, as they declined, indigenous types would fill the vacant spaces. Sometimes hayloft sweepings derived from a good sward were added. During last century seed was made available from a very large number of grass species, and from the eighties onwards highly complex mixtures, containing a dozen or more, with two or three of the clovers (none of them persistent) were commonly recommended. The "discovery" of wild white clover, and its

growing use in the early years of this century, was the first major step of progress in the production of improved long-term leys. Then the work of Gilchrist at Cockle Park, and of Findlay at Aberdeen, resulted in the elimination of many species—some, like meadow fescue, because they failed to compete with other species; others (*e.g.* Italian ryegrass and broad red clover) because they suppressed the more lasting components of the sward; and still others because they were poor in productivity. It should be borne in mind that both workers were thinking in terms of a sward which would be mown in its first year. By a long process of trial and error the two arrived at similar conclusions, and recommended a mixture that was more complex than that formerly used for short leys but much simpler than the typical "permanent" mixtures of the time. The Cockle Park prescription was 14 lb. perennial ryegrass, 8 lb. cocksfoot, 2 lb. timothy, 2 lb. late-flowering red clover, and 1 lb. wild white clover. Sometimes a pound of rough-stalked meadow grass was added, and the proportion of cocksfoot and timothy might be varied according to climate and soil type. This prescription is still the basis of our modern "general purpose" long leys, the chief modifications being the partial or complete substitution of indigenous or pedigree strains of grass for the "commercial" types, the substitution in some cases of S. 100 or other more vigorous strain for the wild white clover, and, in most cases where the sward is to be grazed from the outset, the replacement of part of the perennial ryegrass and late-flowering red clover by Italian (or New Zealand Short-rotation) and broad red clover respectively.

In the traditional ley-farming areas, where severe summer drought is exceptional, such mixtures give very satisfactory results. If a goodly proportion of the first-year grass is mown for hay there will be little difficulty in dealing with the spring flush, and the aftermath will often be sufficient to compensate for the relatively small seasonal decline in output during July and August from the grazed fields. Moreover, the pressure of stock will ordinarily be relieved in July-August by the sale of fat cattle or of fat or store lambs. There is, indeed, the difficulty that really good grazing management is difficult to achieve, the main trouble being with the indispensable cocksfoot. On the one hand, over-grazing by ewes in early spring may so weaken the plant that it fails to perform its function of filling the summer gap. On the other, in seasons when keep is very abundant, fattening

cattle and lambs become rather selective, and the cocksfoot may get out of hand. Where a dairy herd constitutes the bulk of the livestock, and especially if the system of strip grazing (see p. 473) be adopted, these difficulties will not arise.

The following may serve as examples of modern variants of the Cockle Park prescription for the lighter sorts of land. On heavy land timothy would be substituted for part of the cocksfoot :—

	I Grazed Throughout	II Mown in First Years
Italian ryegrass	4	...
Commercial perennial ryegrass	7	8
S. 23 ryegrass	7	8
Danish cocksfoot	3	3
S. 143 cocksfoot	3	3
Broad red clover	2	...
Late-flowering red clover	1	2
S. 100 or New Zealand white clover	1	1
Wild or S. 184 white clover	½	½
	28½	25½

The alternative to the general-purpose ley is two or more complementary or "special-purpose" leys. It is, of course, impossible to suggest any single scheme that would be suitable everywhere since, apart from the wide range of soil and climatic conditions throughout this country, there are such variables as the kind of stock for which provision is to be made; the area, if any, of permanent pasture or meadow which it may be convenient to retain; and the extent to which provision of winter feed is made in the form of arable land products—roots, beet-tops, kale, arable silage, etc.—this last factor, of course, determining the amount of grass that must be preserved by hay-making, ensilage, or artificial drying. Another point for mention is that some replanning of farm layout may be necessitated by a change-over from general-purpose to complementary leys. For instance, if a farm is divided into six "shifts" (three years' ley and three years' arable), and if two complementary leys are to be provided, then each of the fields or blocks will have to be split in two during the period when it is in grass. On the other hand, if the decision is to have three complementary leys then no change of layout will be required, each ley, as it is ploughed out, being replaced by another of the same type.

The characteristics and uses of the commoner special-purpose, simple-mixture leys may be briefly described.

1. *S. 23 Ryegrass with S. 100 or S. 184 White Clover.*—The seed rate, sown without a nurse crop, may be quite low because plants of both species spread out rapidly—8 or 10 lb. ryegrass with 3 or 4 lb. clover is generally adequate if a good tilth can be provided. Sown in spring without a nurse, the sward will produce abundant grazing by midsummer. Thereafter it will be relatively late in spring but will produce abundantly from late April till the end of June and, after being rested, will grow vigorously again in September-October. An important point in management is to avoid over-grazing in the early spring, since this will make for an undesirable degree of dominance by the clover. S. 184 is preferable only for long-duration leys under poor conditions.

2. *Lucerne with S. 37 Cocksfoot.*—The common seed rate is 15 to 18 lb. of lucerne and 3 to 4 lb. of cocksfoot. The cocksfoot will provide early spring grazing, and the succeeding growth will be taken for silage or early hay, preferably the former. The strong aftermath is the best of all insurances against late-summer drought. After resting in September-October the sward will provide further useful grazing. This type of ley is of great value in our driest areas.

3. Under less droughty conditions similar provision may be made for silage and a lush aftermath by means of a mixture of *S. 143 Cocksfoot and S. 100 White Clover* (12 and 3 lb. respectively). The sward in this case will be less useful for early spring grazing, but will yield a heavy and leafy crop for silage and will make very useful provision for the late summer, while the late autumn growth, which will remain green in winters of average severity, can be used at any time from November till March.

4. *S. 48 Timothy, S. 53 Meadow Fescue, and S. 100 Clover* (6, 8, and 3 lb.).—This will produce an excellent cut of leafy hay and a valuable leafy aftermath, which continues to grow well into the autumn.

It will be noted that none of these mixtures includes the very early types of ryegrass (Italian, New Zealand short-rotation, or S. 24) which, given an autumn and winter rest and a dressing of nitrogen in February, are capable of producing grazable herbage earlier than any other grasses. Their disadvantage is,

of course, that they are relatively short-lived. One means of producing early bite is to have a separate field—say a one-year sward of Italian ryegrass or a two-year sward of New Zealand short-rotation—which, if heavily fertilized and rested from October onwards, will produce early bite, followed by a cut of hay and autumn silage or grazing.

SWARDS FOR POULTRY RUNS

Where land is to be laid down for poultry, including ducks or turkeys, a special type of mixture is required. It should be composed of low-growing leafy species with the capacity to produce a close, hard-wearing turf. Where quick establishment is required a suitable prescription is 20 lb. S. 23 perennial ryegrass, 3 lb. creeping red fescue, and 2 lb. of a long-lived strain of white clover. Where rapid establishment is not required a suitable mixture might consist of 12 lb. S. 50 timothy, 3 lb. rough-stalked meadow grass, and again 2 lb. of S. 100 or wild white clover, or 1 lb. of each. Poultry runs, towards the end of each period of rest, should be mown for silage if possible, since if the herbage is left to the hay stage the bottom tends to become open. If the mown herbage is not sufficient in quantity to be ensiled, it should, after mowing, be raked up and put on a compost heap.

SWARDS FOR GRASS DRYING

A grass-drying plant is an expensive piece of equipment, and the larger types require a full-time labour force. It is therefore desirable to keep the drier in full operation, preferably day and night. It is thus an important objective to maintain a regular supply of material, at the young leafy stage of growth, to yield a dried product of high digestibility and high protein-content. This aim can be achieved only with a series of swards with complementary seasons of productivity. In general, the leafy hay and intermediate strains of grasses are to be preferred to the extreme grazing types and, since intensive use is ordinarily made of nitrogen fertilizers, the clover component of the sward is of relatively small importance. In general, there is difficulty in keeping abreast with the growth in spring, but a small area of very early type—Italian or short-rotation ryegrass—is valuable in enabling an early start to be made. These will be followed

by S. 101 and S. 24 ryegrass, to be succeeded in turn perhaps by cocksfoot, and the sequence may then be repeated. Where variations in soil and aspect make for differences in earliness as between field and field, the early mixtures should be sown on the early fields, and the latest mixtures on the latest fields. The summer gap is an even greater problem for the grass-drier than for the grazier, so that, if conditions permit, lucerne should be grown over a considerable area. New stands of ryegrass are the best source of late-autumn herbage. When, as frequently happens in periods of moist warm weather, the drier fails to keep pace with the growth of grass, it is well to make silage rather than let the process get out of step. Further investigation of a grass-drier's problems was still required at the time of writing.

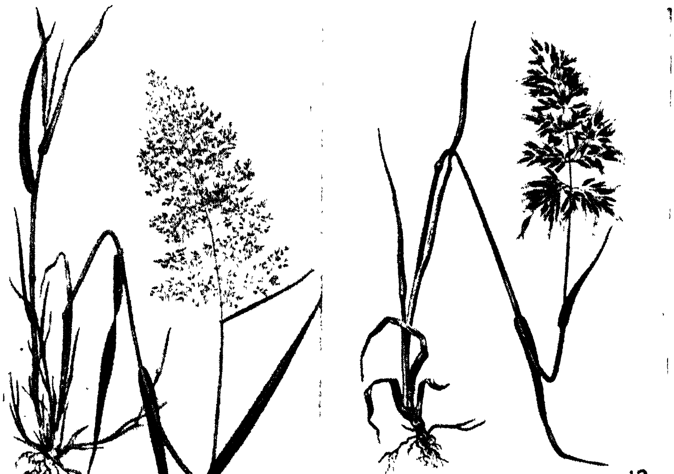
ESTABLISHMENT OF SWARDS

Seeds mixtures may be sown at any time from early spring until late summer; grasses often establish well from autumn or even winter sowing, but clover seedlings are not frost-hardy.

The commonest practice is to sow under a cereal crop. It has sometimes been suggested that a cereal "nurse" protects the grass and clover seedlings from drought, but, in fact, the so-called nurse depletes the soil of moisture and its presence increases the risk of failure. In the cooler areas failures from drought are rare, but in the hotter and drier parts of the country they are common. Hence it is in the latter that the case against the nurse is strongest. A second risk is that of lodging of the grain which, if it occurs some time before harvest, may result in the total disappearance of the clovers, if not of the grasses as well. On land that is in good condition a strong-strawed cereal should be selected. Again the taller and leafier varieties of cereal should be avoided, since the heavy shade that these throw weakens the seedlings, especially the clovers. In northern and upland regions still another hazard must be provided for: the interval between harvest and the onset of winter may be so short that the "seeds" fail to get firmly established and may consequently be winter-killed. Unless, then, it is decided to dispense with the cover-crop altogether, it is necessary to select an early ripening variety of cereal. In higher-rainfall areas the risk from excessive shading is often more serious than that from drought. Hence the taller and more leafy varieties of cereals should be

PLATE XXXIII

9. Timothy 10. Sweet Vernal



Sutton

11. Agrostis 12. Golden Oat Grass

avoided, and the seed rate of the nurse may be reduced to something less than would be employed if the yield of grain were the only consideration.

Sowing without a nurse has been recommended—especially in connection with the establishment of long-duration or permanent swards—for at least a century. It has sometimes been said that this " wastes a year," but in fact the young sward will usually produce a substantial amount of grazing within two or three months of sowing, and, if spring-sown, will reach full production during July and August, at which time succulent young herbage may be of great value. Again, seed rates may well be reduced in the absence of a nurse, because casualties among the seedlings are fewer. Establishment is helped by consolidation of the ground, and hence it is desirable to turn stock on to the land as soon as there is enough growth to serve them ; and it is often good practice to sow a short-lived and quick-growing herbage plant along with the seeds that are intended to form the sward. Such a plant functions as a nurse in a real sense. A bushel of oats, or 6 or 8 lb. of Italian ryegrass, or 2 or 3 lb. of rape, will serve the purpose. Rape is commonly employed where, as in the re-seeding of upland pastures, sowing is often best done in June. The young seeds and rape together will fatten large numbers of lambs.

Annual weeds may, in extreme cases, smother the grass seedlings, but a moderate infestation does no serious harm. Docks and thistles are the most important weeds that infest both ploughland and pastures, but trouble is often encountered with chickweed, red shank, and other species. There is also risk of weed competition in " direct " re-seeding—*i.e.* where the old sward is replaced by a new one without an intervening period of arable cropping. The danger here is that the bent and other poor grasses in the old sward may re-establish and crowd out the seedlings. Under certain conditions this can be prevented by ploughing to a sufficient depth and in such a way as to ensure that the old sod is well covered ; but this may be impossible, more particularly on rough upland. In this case a shallow ploughing and a bastard fallow, followed by deeper ploughing after the sod has been killed, may produce the desired result ; but a surer method is to introduce a " pioneer " crop—*e.g.* of rape—before re-seeding. These procedures are discussed later (pp. 383-385).

As has been said, grass and clover seeds require a seed-bed

that is both fine and firm, conditions that can best be achieved by early ploughing (to permit the land to consolidate and to weather) and by the judicious use of the harrow and roller. Under moist, warm conditions the seeds of grasses will strike even if they are not covered, but clover seeds must be buried. The ideal depth under average conditions is about an inch, but this may be somewhat exceeded in the driest parts of the country.

In cool and moist districts the common practice is to broadcast the seeds, by means of a grass-seed barrow or a "fiddle," and to follow with the harrow and roller. With a very fine soil-crumb, coverage may be difficult to secure, and under such conditions it is good practice to use a ring roller rather than a flat type for the last operation before sowing; a fair proportion of the seed will then come to rest in the little furrows and be covered by the subsequent harrowing and rolling. A machine composed of two gangs of ring rollers, with a seed hopper discharging between them, gives good results. The alternative to broadcasting, and one which is to be preferred in the drier areas, is to drill. If a special small-seed drill (with closely spaced coulters) is not available and a standard drill has to be used, some advantage is gained by drilling in two directions, preferably at an angle of about forty-five degrees. This procedure makes for quicker closing of the sward and therefore reduces the chance of serious invasion by weeds.

Under cool and moist conditions grass seeds may be sown at any time from early spring until about the end of August. Later sowings may give good germination, but the clover seedlings are liable to be winter-killed. In cold and wet uplands June is perhaps the best time. On the other hand, in hot and dry areas early spring sowings are much the most likely to succeed. In the south-eastern counties of England mid-March is not too soon. Where a failure has occurred under a nurse crop, a second sowing may be made—without ploughing—on the stubble. Where patches have failed owing to lodging of the cereal, the sward should be "mended," at the earliest opportunity after the corn harvest, by hand-broadcasting and harrowing or raking.

In certain seasons autumn-sown corn can be successfully under-sown in spring, but it is only on the lighter sorts of land that this can be a regular practice; on strong land the surface, at the time appropriate for sowing, is often too hard to work up into a seed-bed without serious damage to the corn. In general,

the best cereal nurse is a short- and strong-strawed variety of spring barley, sown at a little less than the normal seed rate. Such a crop throws a relatively light shade and, having a low water up-take, leaves a relatively large amount of soil moisture for the under-sown seeds. There is, however, the risk that the young grasses and clovers may grow too luxuriantly and cause great difficulty at harvest. This indeed usually happens when the late summer is wet and harvest is delayed. Broad red clover, being a quick grower and very succulent, is the greatest source of trouble. Another question, the answer to which depends on circumstances, is whether to sow the seeds immediately after the cereal nurse, or to delay for perhaps three weeks, by which time the cereal will be sufficiently well rooted to bear harrowing. If the land is known to contain many annual weed seeds, there is a strong argument for delay, since many of the weed seedlings will be destroyed in the process of harrowing-in the grass seed. Weed destruction by such means is the more to be wished since the common weed-killing sprays may cause damage to the clover seedlings. Again, late sowing reduces the risk, referred to above, of an over-luxuriant growth of clover at harvest. On the other hand, and especially in the drier areas, delay in sowing greatly increases the chance of a failure to get a "take."

The better grasses, to make vigorous growth in the seedling stage, require a high status of soil nutrients and a neutral or only slightly acid soil reaction. When sown without a nurse, the young plant should be grazed as soon as the plants are tall enough to provide a bite for cattle, since the treading of animals, at times when the land is dry enough to carry them without poaching, is beneficial. Excessively close grazing by sheep may, however, weaken the plants unduly. Seeds sown with a nurse may often be grazed in autumn after the corn crop has been cleared, but much depends on the period of growing weather that can be expected; in late districts, where there is only a short interval between harvest and the onset of winter, it may be well to leave the autumn growth untouched. Moreover, severe autumn grazing will so weaken the plants that spring growth will be slow, and the "early bite" from young seeds is usually more valuable than autumn keep.

Treatment of sown pastures in their first harvest year is also important. In general, the best swards are produced by grazing, but on some types of land the young turf is too "tender" to

carry cattle. The main long-term objective is to prevent the suppression of the white clover, which is liable to occur if the sward is laid up for hay in its first year, more especially when mowing has to wait for settled weather until the crop has passed the proper hay stage. In general, it is better to cut for silage, since this can and should be done at an earlier stage of growth. The aftermath should be rather closely grazed, but not up till the very end of the growing season. In general, lenient grazing will encourage the grasses, while continuous hard grazing, by removing the competition of the grasses, will encourage the prostrate white clover.

MANURING AND MANAGEMENT

Principles of Grazing Management.—An understanding of some biological principles and processes is a necessary foundation to good grassland management, and these may be illustrated by reference to a ryegrass-clover sward.

In autumn herbage plants lay up reserves of food material —mainly carbohydrate—in their roots, stolons, and leaf bases. The amount of these reserves is dependent upon the amount of active leaf tissue and on the length of time during which conditions (light, temperature, and soil moisture) enable photosynthesis to continue. Accordingly, if the sward is grazed hard and continuously during the latter part of the season, and up till the onset of winter, the plants' accumulated reserves will be small and, in consequence, spring growth will be feeble. Again, it should be remembered that the leafage which ryegrass throws up during mild periods in winter is produced mainly at the expense of food reserves. If this winter growth is eaten off, the plants will be further weakened.

Ryegrass commences active spring growth when the soil temperature reaches a figure of about 44° F., but the rate of growth is determined, not only by soil and air temperature and by light, but also by the supply of available soil nitrogen. Under typical British conditions, however, soil nitrates are almost completely leached by winter rains, and the bacterial activity by which the stock is replenished begins only when the soil temperature has risen to about 48° F. There is thus a period, longer or shorter according to the rate at which the soil warms up, during which (while the clover will in any case remain dormant) the production of grazable herbage is dependent upon the application of nitrogen

in a readily available form. The production of "early bite" thus depends on three things, viz.: (1) the presence in the sward of naturally "early" types of grasses such as ryegrass; (2) the resting of the sward in autumn and winter; and (3) the application, preferably in February or early March, of quick-acting nitrogen fertilizer. A common dressing is 1 to 2 cwt. of sulphate of ammonia or Nitro-chalk.

The subsequent effects of such treatment must also be borne in mind; if the ryegrass is forced into early growth and is then severely and continuously grazed, it will be weakened at a time when the white clover is still dormant; and when, later, the clover comes into growth, it will be in a strongly competitive condition and will tend to dominate the sward. The restoration of a good balance can be assisted by lenient grazing in summer or by laying up the field for a cut of silage; but it is generally inadvisable to treat a given field repeatedly, in successive years, in the way described. It will also be readily understood that if the early growth of ryegrass is not grazed, the balance of the sward will be upset in the opposite sense—*i.e.* the ryegrass will overtop and suppress the clover. Incidentally, it will also be obvious that the problem of maintaining a balanced sward can be avoided by using, for early bite, a pure-grass sward. Many farmers rely upon Italian or New Zealand short-rotation ryegrass for the purpose, these types making earlier spring growth than any of the strains of perennial grasses.

To turn from the early spring to the main grazing period—say from May till October—it must be recognized that, with a given botanical composition and a given level of fertilizer usage, the nutritive value of the herbage per pound of dry matter, and also the total yield of nutrients per acre, depend largely upon the system of grazing adopted; but, again, that maximum yield of nutrients is not fully compatible with maximum nutritive quality. The percentage of protein is highest and that of crude fibre is lowest in the young leaf—*i.e.* at the shortest and earliest stage of growth that will allow the animal to satisfy its appetite. But if grazing is so intense as to maintain a lawn-like condition the leaf area will be kept small, so that carbon assimilation is depressed. This will, in turn, be reflected in feeble root growth and lowered capacity to resist drought. By contrast, the highest yields of nutrients per acre are obtained, in cutting experiments, with two or three cuts per season, the first being made about the

time of emergence of the flower heads. Management based upon such considerations is not always practicable, if only because of the excessive waste by soiling and treading that would result. Moreover, animals thrive best when they have "full bite" and no more, *i.e.* when they can fill themselves in a short time and yet are not tempted by the abundance of keep to become highly selective. "Full bite" implies a length of about 5 to 7 in. for mature cattle and less than half this length for lambs.

Since deep-milking cows and also fattening cattle and sheep require highly concentrated diets, and since supplies and prices of oilcakes, cereals, etc., preclude their large-scale use in summer, pasture management for these groups must aim at the production of highly nutritious herbage even though this will imply some reduction in the output of total nutrients per acre. By contrast, dry cows, two-year-old heifers, and store stock can maintain themselves in satisfactory condition on a less nutritious diet, and larger numbers can be carried if the grazing is relatively lenient.

The major difficulties in achieving the desired degree of intensity of grazing arise from the fact that the rate of growth of pasture herbage varies from month to month during the average year, and varies also—especially during the midsummer period—as between one year and another. Variation during the season is at its maximum on the thinner and lighter soils of the drier and warmer (south-eastern) districts and in the low-rainfall pockets that occur in the Midlands and elsewhere. Under the least favourable conditions production during the period May-June may amount to 50 or even 60 per cent. of the year's total. As said earlier, the growth of ryegrass may come to a complete standstill in July-August. In the cooler and moister parts of the country the production curve shows less violent ups and downs, but is never anything like level.

The traditional method of levelling out the seasonal supply of pasturage has been to mow for hay some proportion—up to about half—of the total grass area, and to use the aftermath for grazing; but the hay crop, by reason of its high rate of transpiration at what is ordinarily the driest part of the year, often leaves the soil with very little moisture, so that the growth of aftermath may be delayed until there is a good rain. Moreover, the plants use up, in the formation of their stems and flower-heads, a substantial proportion of their carbohydrate reserves, and the extent of this exhaustion is increased if the plants are allowed to set seed—as

they will, of course, do whenever mowing is delayed by unsettled weather. All this explains the unreliability of hay aftermaths for the purpose of filling the summer gap in the supply of pasturage. As said earlier, the most certain means to the desired end is to provide a second sward, composed of drought-resistant species, as a complement to the ryegrass-clover type, and to mow this, before ear-emergence is complete, for ensilage. At the season in question there will be, in most seasons, a fair supply of soil moisture, and the plants will have sufficient food reserves to enable their quick recovery after mowing.

Another important aim of pasture management is to ensure that the herbage will, in fact, be consumed at the desired stage of growth. The ideal is to allow successive crops to grow undisturbed—*i.e.* to give the sward periods of complete rest—and to harvest each successive crop, by means of grazing animals, quickly and completely. The procedure is thus essentially the same as that of folding sheep on clover, etc.

Traditional systems of grazing management fall short of the ideal in varying degrees, and practical considerations often prevent its attainment. One fact is that different kinds of grazing animals are more or less selective in their feeding habits. Horses are extremely so. From the start of the season they usually concentrate on particular large patches and completely neglect others—upon which they usually dung. They prefer young growth to old and bite very close, so that the final result, where a field is stocked with horses alone, is a mosaic of lawn-like and rough, neglected patches. Sheep are also highly selective, but after another fashion—picking out individual plants, shoots, and leaves, and, in particular, avoiding the flowering stems of the grasses. Sheep pastures must be topped by the mower if the grasses are to be prevented from wasting their energies on seed production. Cows in milk are not very fastidious, but if they are compelled to clear up rough or soiled herbage their milk yield falls—often quite abruptly. Two-year-old store cattle, dry cows, and in-calf heifers in the earlier stages of pregnancy can, without suffering harm, play a useful role as scavengers.

Where relatively large groups of stock are allotted to particular fields, with the intention of leaving them for a period of perhaps two or three months, suitable combinations are fattening cattle with a few sheep or, alternatively, a flock of ewes and lambs with a few store cattle or suckling cows with their calves. If it appears

that the farm stock as a whole is inadequate to keep the pastures under control—as will happen in a warm and moist season—some concentration will be required, and a field or two should be laid up, preferably for a silage cut.

A refinement of the system of free-range grazing is found in areas that specialize in the grass fattening of cattle, particularly in the Midlands. The store animals are kept during early spring in " holding fields " of relatively poor grass, being given hay if necessary, until the fattening swards commence active growth, which they commonly do in late April or early May. Numbers are adjusted with the object of maintaining control of the growth during the spring flush period. Meanwhile, however, a reserve of cattle is carried on one or two of the holding fields, the rest being laid up for hay. The usual aim is to have a proportion of the cattle in forward condition at turning-on time, so that these may be sold fat towards the end of the flush season, and thus leave a sufficiency of feed for the remainder. Many graziers also keep a relatively small flock of draft ewes, which go off fat with their lambs soon after midsummer and thus give further relief. It is the general belief that fattening cattle make the most rapid progress if they can be left in the same fields throughout their fattening period. Another point is that shade should be provided as a protection against gad flies. The fattening fields are " cleaned up " by lean cattle in autumn, and are either completely rested throughout the winter or carry only a few ewes—rarely more than one per acre.

Another traditional system, for which there is less to be said, is common on small dairy farms. Two enclosures provide for the needs of the milking herd—a relatively small night paddock and a large day pasture. A third field, usually of poorer quality, is allocated to the heifers and dry cows. The remainder of the grassland is used for hay, and the aftermath is expected to fill the summer gap. This plan gives very limited scope for controlled grazing, and the night paddock commonly collects fertility from the day pasture. An improvement on this scheme, which is feasible in many cases, is to divide the grassland—apart from the night paddock where this must be retained as a matter of convenience—into perhaps six or seven enclosures. These are used in rotation, each in turn being grazed first by the milking herd and immediately afterwards by the " followers," and then rested for about three or four weeks. During the flush period

growth may be controlled by laying up, for a silage cut, any piece that is not needed as pasturage. The scheme, moreover, makes practicable the use of summer dressings of nitrogen, whereby growth can be stimulated in summer and autumn according to need; and it makes possible the ploughing up and re-seeding of each enclosure in turn.

In general, however, still better control, with a substantially higher output of milk per acre, can be secured by the system of strip grazing, whereby the daily or half-daily ration of pasturage is provided by the step-by-step movement of a fence that consists of a single electrically charged wire, on easily movable and insulated supports. The longer the fence and the narrower the strips the less will be the wastage through soiling and treading. A "back fence" should preferably be used in order to prevent access by the herd to ground which it has recently traversed. The area provided at each move must, of course, be adjusted, partly by trial and error, to the herd's daily (or half-daily) needs; but with a close sward at the optimum stage for grazing—about 6 in. high—a first approximation might be one-sixtieth of an acre per cow per day. It is necessary to plan ahead and to mow, for silage or drying, any area that is likely to be unwanted, or that is passing the optimum growth stage for pasturage by the time it is required for grazing. Records show that the gain in output by substituting strip for free-range grazing, expressed in terms of milk per acre, is of the order of 20 to 25 per cent.

A strip-grazed herd may include dry cows and in-calf heifers, but there are difficulties in applying the system to other classes of stock. The dairy herd must in any case travel twice daily from shed to pasture, giving four opportunities for watering; moreover, during "fly weather" the cattle can be kept in the shed, or given access to shade, during the heat of the day. But problems of water and shade arise in the case of store or fattening cattle, and sheep are less effectively controlled by any existing type of fence that is easily movable. It seems, however, that the improvement of output, under strip grazing, is of the same order with store and fattening stock as with milch cows.

Manuring of Pasture.—Lime is lost from grassland by leaching at much the same rate, other things being equal, as from arable ground; but the lime status required even for the better sort of grasses and clovers—about *p*H 5·5 to 6—is lower than that needed by such crops as sugar-beet and barley. Lucerne

and sainfoin, among pasture plants, are exceptions, giving optimum results on neutral or slightly alkaline soils. The symptoms of moderate lime deficiency are less obvious in grasses and clovers than they are in most arable crops, so that soil tests for lime are more often required. In extreme cases the disappearance of the better species, the presence of sorrel or of *Holcus mollis*, and the formation of a surface " mat " of dead but undecayed material, are sure signs. The intrusion of the sward by *Agrostis*, which is the commonest form of deterioration, is often due to causes other than acidity—to phosphate deficiency or to over-grazing in winter combined with under-grazing in summer. The general rule about liming—that frequent and moderate dressings are better than mass applications at longer intervals—applies equally to grass and arable land.

With soil of reasonably good " body," and where the grazing stock is composed of store or fattening cattle or sheep, losses of potash are very low, practically the whole amount consumed being returned to the land in the urine. By contrast, milch cows pass a good deal of urine in the cowshed, or in course of their travels between shed and pasture, with the consequence that most dairy pastures require periodic dressings. Obviously, also, if grassland is mown for any purpose, without getting dung in exchange, the drain on potash reserves will be large. Even an occasional cut of hay, unless this is fed back on the land where it has grown, will result in potash depletion. The species most susceptible to potash deficiency are lucerne and red clover.

Response of pasture to dressings of common salt has sometimes been reported, but in most cases these, if real, have been very small. Salt has sometimes been used to induce store cattle to clean up otherwise unpalatable herbage.

Losses of phosphate by true leaching are small, but it may be noted that, on steep slopes and especially where the soil is light or stony, substantial amounts may be carried away in suspension by surface or sub-surface water. Growing animals retain substantial amounts of phosphate in their bones, and milch cattle also make considerable demands; a cow producing 500 gals. of milk during the grazing season will deplete the soil of the equivalent of about half a hundredweight of superphosphate. Full-grown fattening animals, on the other hand, excrete practically all the phosphate that they consume.

It has already been pointed out (p. 42) that most British soils

have a marked capacity to fix phosphate in unavailable forms, so that a simple balance-sheet of gains and losses has often very little meaning. In fact, the only pastures that do not need regular applications are on soils of high phosphate status and low powers of phosphate fixation, and where the land is regularly stocked with mature non-milking stock.

Soil surveys and field experiments show that, despite the relatively high rate of usage during the past decade, much of our poorer grassland is still markedly phosphate-deficient. Where such marked deficiencies have to be made good, suitable sources are ground mineral phosphates for the typically rather acid soils of the high-rainfall areas, and high-soluble basic slag elsewhere. Where there is no such gross deficiency, and only "maintenance" applications are required, the evidence is in favour of small dressings at short and regular intervals. In such cases it is often convenient to use either superphosphate alone or a compound fertilizer containing soluble phosphate. Under intensive systems of management phosphate is generally applied in the form of compounds with nitrogen or with both nitrogen and potash.

Policies in regard to nitrogen usage vary very widely, and the choice for the particular farm depends largely on economic considerations and individual circumstances. On the one hand, a well-balanced clover-grass sward can be self-supporting in regard to nitrogen—*i.e.* the needs of the grasses can be met, throughout the greater part of the season, by the nitrogen fixed by the clover and later made available either in the form of "stock nitrogen" (mainly urine) or by the decay of clover nodules and leaves. New Zealand workers have shown that, under the very favourable prevailing conditions, the clover in a balanced sward may fix as much as 200 or 300 lb. of nitrogen (equivalent to 10 to 15 cwt. of ammonium sulphate) per acre during the nine or ten months that the plants continue in active growth.

Under British conditions the amount fixed is ordinarily much less, and the loss by leaching during our much longer dead season must be considerably higher. Nevertheless, with adequate supplies of lime and phosphate (upon which the growth of clover so greatly depends), and with competent grazing management, quite high outputs of livestock products can be attained without resort to nitrogen fertilizers. Overall production is, however, not the sole consideration, especially where, as in the case of a dairy herd, a high level of nutrition must be maintained week by week

throughout the year. April grass, grown with the help of applied nitrogen, will necessarily be more expensive than June grass grown without, but will ordinarily be much cheaper than the equivalent in the form of hay and concentrates. Again, if growth can be sustained throughout the late summer, and again into the late autumn, a considerable saving of more expensive alternative foodstuffs will be achieved. It will often, then, be good business to plan for the " early bite " on the lines previously discussed (p. 468), to top-dress such fields (*e.g.* of cocksfoot) that are shut up in late May with the object of filling the summer gap, and to stimulate the autumn growth of a ryegrass ley by an August application. In other words, nitrogen can be used to increase the amount of grazing at the periods when keep is liable to be short. To this end the greater part of the acreage allotted to the dairy herd will be top-dressed at one time or another during the year.

The policy indicated above is rarely applied as a matter of routine where the grazing stock consists of store or fattening cattle or sheep. Store cattle due for turning out in spring, whether or not they are intended for summer fattening, can generally be held, at no very great expense, until the time when an ordinary pasture has produced a good bite; only in years when winter fodder is likely to be short is there a strong case for forcing early growth; and the stocking can often be reduced, by sales, to ease the pressure on the pastures in late summer.

In the case of lowland flocks of breeding sheep there is often a good deal to be gained by applying a February-March top-dressing to some part of the pasture, ewes being often short of milk up till the commencement of spring growth. The risk is that herbage which has been forced with nitrogen may cause scouring in lambs when they begin to graze freely; if this is to be feared, the flock should be moved daily to and fro between two pastures, only one of which has been treated.

Many milk producers, especially those whose acreage is small in relation to their available capital, have adopted a system of manuring much more intensive than anything described above. In such cases it is essential to resort to rotational or strip grazing in order to maintain proper control of the sward. A common programme is to apply, about February, a substantial amount of compound fertilizer—for example, 4 to 5 cwt. of National Compound No. 1—and to follow with two or more applications

of nitrogen, providing perhaps 50 to 70 lb. nitrogen per acre during the season. Nitro-chalk or nitrate of soda is to be preferred to sulphate of ammonia, the response to the latter being too dependent on rain. Such farmers have generally a strong preference for leys of three or, at most, four years' duration, mainly because the clover, being at a disadvantage in competition with the grasses, is often almost completely suppressed after three years.

Such a combination of treatments—high fertilizer usage with complete grazing control—may be expected, in the cooler and moister areas, to raise the output of milk per acre to something more than double the traditional figure. In the hotter and drier areas, and especially, of course, where the soil is light, the achievement of the full benefit depends on irrigation, which is likely to be economic only under conditions that are not general—*e.g.* on fields adjoining streams.

Grassland for Mowing.—We now pass to the production of material for hay or silage. Production for artificial drying is so closely bound up with the drying process that it is more conveniently discussed in the next chapter.

Permanent Grass for Mowing.—The acreage of meadow hay has in recent years shown a marked fall—from about 5 million acres in 1939 to about 3 million acres in 1953. The latter figure, however, represents about 10 per cent. of the total agricultural area. The level of production from typical old meadows is low. It is true that part of the acreage mown will have yielded some grazing before being laid up, and also that the aftermath will normally be grazed. Even so, an average yield of little more than 1 ton, providing perhaps 6 to 7 cwt. of starch equivalent and about 1 cwt. protein equivalent per acre, suggests that some other type of production should be preferred if circumstances permit.

Most permanent swards have obvious shortcomings when regarded as sources of hay. They contain a large number of grass species whose flowering times are spread over many weeks, so that there is no particular date when a large majority are at the optimum stage for mowing—*i.e.* the commencement of flowering. Again, some of the earliest-flowering species—sweet vernal and Yorkshire Fog—are weeds, and these will be ready to shed their seeds before the later-flowering among the good grasses—*e.g.* timothy—are ready to mow. Many weeds that cannot bear close grazing or treading, and therefore cause no trouble in pastures,

multiply rapidly in swards that are regularly mown. Again, as was said earlier, white clover is the only true perennial among the useful legumes, and the wild forms occurring in old swards are so prostrate that they contribute little to the mown swath, and what is reached by the mower knife is largely composed of single leaves that are easily lost in the process of hay-making. Obviously, too, any treatment that produces a good growth of grass will result in the suppression of the clover. The argument in favour of young, sown swards is thus stronger for meadows than for pastures.

In particular cases, however, circumstances virtually dictate mowing year after year. For instance, the small amount of low ground that is attached to the typical mountain sheep farm must often serve the double purpose of providing grazing during the "starvation period" in spring and yielding a stock of hay against periods of severe winter weather. Again, there is land which is either liable to flood, or which is dry enough to carry grazing animals only in late summer and autumn. The lack of drinking water for cattle is another common reason for continuous mowing.

The appropriate fertilizer treatment for meadow land will generally be different from that for pasture, even under similar soil and climatic conditions. Unless the hay crop is consumed in the field where it has grown, the taking of successive crops will rapidly deplete reserves of available potash, which depletion does not arise in the case of pasture. Again, it is not to be expected that, under meadow conditions, wild white clover will persist in sufficiently vigorous condition to provide enough nitrogen for the grasses. In general, then, meadows should have regular dressings of dung—perhaps at intervals of four years—supplemented by potash and nitrogen fertilizers as well as phosphates.

In cases where the permanent grass area of a farm is fairly uniform, and where water can be provided in every field, the question arises whether it is better to allocate particular fields as meadow and pasture respectively or whether each field should be mown one year and then grazed for a year or more. Both schemes have their advocates. On the one hand the alternate system, with good management, makes possible the maintenance of a reasonable grass-clover balance in the sward, with lower expenditure on nitrogen fertilizers for a given level of production. Moreover, alternation results in better weed control. The

competition of a tall hay crop, combined with cutting at a critical time, greatly checks the growth of stoloniferous species like field thistle, while the combination of close grazing and treading kills out erect-growing species that have no underground stems—*e.g.* yellow rattle. On the other hand, most of the desirable pasture species, which withstand treading and close grazing by reason of their prostrate growth habit, or because their growing points are at or below ground-level (notably the indigenous types of ryegrass and white clover), are by no means ideal hay plants; a good deal of their leafage escapes the mower knife, and the short leafy material is difficult to cure and collect.

As said earlier, mowing at the "silage stage" rarely causes serious deterioration of a grazing sward, whereas mowing for hay does a lesser or greater amount of harm according to the growth stage that the plants are allowed to reach. If the maintenance of high-quality swards were the sole consideration all surplus grass should be ensiled, hay-making being abandoned altogether. This step has, in fact, been taken by some few farmers, but it is not generally practicable. For one thing, if the product has to be hauled a long way—to the farm buildings or perhaps to a hill or mountain grazing—the greater weight of the silage (three times that of hay) is a consideration. A more general difficulty is that of providing the necessary labour and equipment to deal with the whole area that is to be mown before the herbage has passed the proper growth stage for ensilage.

Where a sward—temporary or permanent—is to be mown every year, the system of manuring and management will depend upon the relative importance which the farmer attaches to the yield of hay on the one hand and, on the other, to the amount and quality of autumn, winter, or spring grazing. The production of maximum hay yields implies a large usage of nitrogen fertilizers and leads to the suppression of white clover and the more prostrate types of grasses. The highest yields of hay—up to 4 or 5 tons per acre—are obtained from timothy meadows which, in addition to liberal dressings of mineral fertilizers, are ordinarily given nitrogen equivalent to 3 or 4 cwts. per acre of ammonium sulphate. Any clover sown is quickly suppressed, and the timothy itself produces only a small aftermath. At the other extreme are the enclosed "in bye" grasslands attached to mountain grazings, on which the farmer depends for wintering and often also for the keep of part (or even the whole) of the flock at lambing time

in addition to a crop of hay. Here the usual scheme of manuring omits nitrogen fertilizers entirely, but if the stock includes house-wintered cattle there will be an occasional dressing of dung. Permanent meadows on lowland farms are generally treated on some intermediate plan. A four-year plan might include a dressing of dung the first year, a light dressing of nitrogen the second, a substantial application of balanced artificial in the third, and nitrogen alone again in the fourth.

Seeds Hay.—The term "seeds" is usually applied to hay that is taken from temporary grassland, though in some cases it is meant to refer in particular to a crop taken in the first harvest year. In this case "second year" or "third year" are applied to the produce of subsequent years.

Even when land is sown down with the primary object of producing hay, a certain amount of grazing is usually provided. Grazing in the autumn of the seeding year assists establishment and, where there is a considerable proportion of red clover, reduces the incidence of clover rot. The young seeds should be rested over winter, or at least should not be heavily grazed. Where hay is to be taken in the first harvest year the question arises whether the spring growth should first be grazed. The answer depends largely on soil and rainfall conditions. On thin, poor soils and in dry areas spring grazing tends to depress the grasses and weaken their root systems, thus making for a too clovery sward and leading to a reduced yield of hay. On good, deep soil in areas of high rainfall it ordinarily does little harm, and may indeed prevent a crop from becoming over-luxuriant and perhaps lodging and rotting at the bottom. The normal practice in dry areas is to "shut up," about Christmas, seeds fields that are intended for hay in the following season, whereas in cool upland regions the field may be grazed as late as the beginning of May. Chain harrowing and rolling should be done in spring in order to consolidate the ground and leave a smooth surface for the mower.

Where hay is to be taken in the first harvest year of a ley that is to lie for two or more years, thought must be given to the maintenance of balance in the sward. If a heavy dressing of nitrogen be given, if cutting be delayed beyond the flowering time of the early grasses, and if the aftermath be allowed to grow to a considerable height, the ryegrass will tend to suppress the white clover, with the consequence that subsequent production

will be seriously impaired. The general aim should therefore be to mow early and to stock the aftermath as soon as there is a good bite. Full productivity during the first season is much more fully compatible with the maintenance of sward balance if the first growth is taken for silage.

As regards manuring, it is usual to provide for the initial needs of a ley in regard to lime, phosphate, and potash at the time of sowing—the requirements of the grasses and clovers, as well as those of the nurse crop, being met by a single dressing. Alternatively, mineral fertilizers may be applied to the young seeds in autumn—as soon as convenient after the corn harvest. If the ley is to be grazed in its second and subsequent years after being mown in the first, nitrogen must be used with discretion, otherwise the white clover may be suppressed. Under average conditions about 1 cwt. of ammonium sulphate, or the equivalent in other form, is common.

It is the common practice, with dual-purpose leys, to take hay in the first harvest season and to graze in the subsequent years; and this is certainly desirable when the grazing stock is mainly cattle and where soil and rainfall conditions make the young sward liable to serious damage by treading. Where, however, there is a poor "take" of white clover, grazing in the first year will help greatly to secure a good balance. Where such considerations do not arise there is a case for grazing the first year and mowing in the last. One argument is that, since there is no need to maintain botanical balance in the last year, the management may be planned with the sole objective of a heavy hay crop—*i.e.* the field may be rested in spring and given a heavy dressing of nitrogen. Moreover, the resultant sod may be of more value, as a source of soil fertility to the succeeding arable crops, than that produced by grazing. A closely grazed and clovery sod decays very quickly and releases nitrogen in such amount that the following crop, if a cereal, may be so luxuriant as to lodge badly. A grassy sod decays more slowly. Moreover, the grasses, if allowed to grow to the hay stage, leave a large mass of fibrous root material that has a long-lasting effect on soil structure.

Grassland Improvement.—It has already been explained that it is only under particular conditions of soil and climate, and under systems of management that are not always practicable, that a high level of grassland productivity can be maintained indefinitely. Under most sets of circumstances inferior grasses

(bent, dogstail, Yorkshire fog, or sheep's fescue) increase at the expense of the better species, miscellaneous weeds increase, and the proportion of clover falls below the optimum.

There are three possible approaches to the problem. The one is to bring the largest possible proportion of the farm under a system of alternate husbandry, thus reducing the area of permanent grass. The second is to plough out and directly re-seed such fields as, for one reason or another, are unsuited to arable cropping. The third is to supplement the use of lime and fertilizers and good normal sward management with occasional drastic surface treatment and perhaps to introduce a certain amount of seed. The last of these procedures is the least effective and should be resorted to only where the land is practically unploughable. The subject of the following paragraphs is the improvement of lowland and upland pastures in cases where deterioration has gone far. The improvement of hill and mountain grazings is discussed later.

In some cases a major cause of deterioration is the disrepair of the drainage system, and where this has happened reconditioning must be the first step. The common signs of inadequate drainage are the occurrence of rushes and tussock grass. It may be that a complete new drainage system will be required, but there are many fields where a thorough clearance of the ditches, together with minor repairs to old tile drains, will meet the need. The standard of drainage required for grass is not as high as for arable land. The second step must be the correction of any serious lime deficiency, and a lime survey of the land will often be desirable, particularly since the lime status may vary widely from place to place. The phosphate and potash requirements should be ascertained at the same time. Extreme phosphate deficiency is common, whereas (except in old hay meadows) serious potash deficiency is rare. If the land is to be ploughed and re-seeded, some part of the lime should preferably be applied before ploughing and the balance after. The clearance of scrub, where necessary, must also, of course, precede ploughing. In many cases the cheapest method is to pull out the bushes by means of several ropes, each operated by a man, attached to a tractor.

Ploughing may be ruled out by outcrops of rock, by the occurrence of large numbers of boulders, or by excessively steep slopes, but it should be done if possible; moreover, the quality of the work is important; if possible the sward should be

completely buried, since otherwise bent and other poor species will grow and spread before the sown grasses have become established. If complete burial cannot be achieved seeding must be delayed, and discs must be used during the interval to ensure a complete kill of the old herbage. Indeed, where this difficulty is foreseen, it may be best to disc the land two or three times during the first summer of operation and to defer ploughing until a fairly complete kill of the old herbage has been achieved. In any case, ploughing should be carried out in autumn so that the land may have time to consolidate before sowing in the following spring or summer. Phosphate, and potash if necessary, should be applied soon after ploughing.

Preparation of the seed-bed in spring should in any case begin with discing, since tined implements are apt to bring up pieces of old turf; moreover, discs produce the better consolidation. A dressing of nitrogen should be given at seed-time. Since the treading of grazing stock assists establishment, it is important to include the seed of some fast-growing herbage plant which will provide grazing at the earliest possible date. A bushel of oats or about 10 lb. of Italian ryegrass per acre will serve the purpose. In cool upland districts, where sowing is late, rape is frequently used as the nurse, producing useful keep for weaned lambs; but if the rape is intended to reach full growth only about 2 or 3 lb. per acre should be sown. Heavier seed rates, unless the land is to be stocked while the plants are still small, may have a depressing effect on the young grasses and more especially on the clovers. In drier lowland areas the seeds should be sown early—March or early April—whereas in cold and wet upland districts June may be the best time.

A special case, common in upland areas, is presented by land that is heavily infested with bracken, when the preparations for re-seeding must be designed to eradicate the weed. Here the time of ploughing is critical, the best being late June. In some cases a catch crop of rape may be grown in the same season, the sowing of the grasses being delayed until the following year. Indeed, where the land is very poor, and has been acid for a long period, it may be well to grow two "pioneer" crops—first rape and then perhaps broadcast kale and turnips, and to eat these off with sheep in order to achieve the necessary build-up of fertility.

Where ploughing is impracticable the improver must have recourse to surface treatment as a preparation for sowing.

Drainage and liming must be carried out if necessary, and fertilizer dressings must be applied. The mechanical treatment required depends largely on the presence or absence of "mat"—*i.e.* of a surface layer of dead but undecayed vegetation; "mat" is, of course, indicative of severe lime deficiency. In the absence of a "mat" the choice of method depends on the proportions of good and bad species, and especially on the presence or absence of white clover. If the botanical composition is reasonably good, satisfactory results may be expected from the following procedure, viz. (1) the sward is closely grazed, in autumn, by lean animals; (2) phosphates and potash are applied in the quantities indicated by the soil analysis; (3) a moderate dressing of nitrogen is applied in spring and the land is harrowed sufficiently to break the surface, but not so severely as to drag out any considerable number of plants; (4) the field is closely grazed and completely rested by turns throughout the grazing season and is rested during the succeeding winter.

Still assuming the absence of "mat," but with a predominance of poor species, the foregoing plan must be changed in three respects. Firstly, surface treatment must be more drastic, including generally the use of a heavy disc (in both directions) in addition to spike harrows. Secondly, the appropriate species—including especially wild white clover—must be introduced; a suitable "renovating" mixture might include 2 lb. of wild white clover, 5 lb. of indigenous ryegrass, and a few pounds of some other appropriate species of grass. Thirdly, the seed must be buried, preferably by means of a chain-tooth harrow, and the land must then be heavily rolled.

The combination of poor species, a thick "mat," and unploughable land obviously presents a most difficult problem, and quick results cannot be looked for. Some time before beginning mechanical treatment—a year or even two—the land should have lime and phosphate according to need. The next preparatory step is to clean off the top growth, either through close grazing and treading by lean cattle receiving some supplementary feed, or alternatively by burning off in late autumn or early spring. The "mat" is next cut up and moved by repeated discings, if possible in two or more directions, and its break-up is carried further by means of a chain-tooth harrow or a rotary cultivator. A catch crop—*e.g.* of rape and Italian ryegrass—is now sown (in early summer) with a moderate

dressing of nitrogen. When the resulting crop has been fed off, and the fertility of the land has thus been improved, the land is reworked with discs and harrows, and is re-seeded in spring or early summer with a "permanent" mixture, along with the usual amount of oats, Italian ryegrass, or rape to yield grazing as early as may be.

Maintenance and Improvement of Hill and Mountain Grazings.—At the beginning of this chapter, in the description of types of mountain herbage, it was pointed out that heather is kept in good condition by burning at fairly long intervals, that *Molinia* may have to be burned from time to time, and that *Nardus* remains almost unproductive unless it is burned relatively frequently. The optimum interval between the burnings depends on the condition and rate of growth of the herbage; for example, the rotations adopted for burning heather vary from five to over twenty years. The usual time for the treatment is in March and April, but in some of the wettest parts of the country it is difficult to get a sufficiently dry spell for the heather to burn at all. Sheep thrive better and losses are smaller on grazings that are regularly burnt.

Surface or "sheep" drains are dug on upland pastures, not on the hill as a whole but only on such parts as are likely to benefit. For instance, where a spring is causing a rush-covered swamp, a drain may be cut to divert it to the nearest waterway. Sheep drains should be about 20 in. wide at the top, 6 in. at the bottom, and fully 1 ft. deep. The Cuthbertson plough, drawn by a crawler tractor, is a very satisfactory tool for making sheep drains; its use effects a great economy as compared with hand labour. Channels are cut to spread as well as to remove moisture. If water that springs from basic rock is distributed over the typical flora of acid soil a very great improvement is effected. The "flushing" is brought about by digging a channel from the spring along the contour and by causing it to fill and overflow so that the water soaks down the slope. Sheep generally graze the flushed area very hard, and this may contribute to the improvement, which consists largely in a reduction of poor species like *Nardus* and blaeberry and in a corresponding increase of useful grasses.

Where uplands are grazed by cattle as well as sheep the pasture is kept in much better condition. This is because the larger animals eat the coarser kind of herbage that, in their absence,

would not only be neglected but would actually spread and reduce the area that is useful for sheep.

It will commonly be quite uneconomic to deal with any very large part of a hill or mountain grazing by the methods outlined earlier (pp. 481-484). Much, however, can be done in certain cases by the treatment of carefully selected areas whether by lime and fertilizer only, by lime, fertilizer and surface treatment, or by the latter combined with re-seeding. In any case, some degree of grazing control is necessary to prevent the extermination of the better species by persistent over-grazing. It should be borne in mind that even the partial replacement of *Nardus*, *Molinia*, or Sheep's fescue by *Agrostis*-clover constitutes a major step of improvement; and this can sometimes be achieved at no very great expense. The track-laying tractor, and also special equipment for wheeled tractors, has made possible the ploughing or the "roughing up" (by discs or pitch-pole harrows) of land that could not have been cultivated by older types of tackle. A major remaining obstacle is the high cost of fencing, each separately, the many small patches of improvable land, so as to protect the improved swards from being "grazed to death." In some cases, however, it is possible to concentrate the improved patches in one particular section of the hill, to fence off this section as a whole, and to unstock it—*e.g.* in the late summer and autumn—when the flock can be restricted, without suffering harm, to the unimproved land. The control of stock on hill pastures is more fully discussed later (p. 694).

Control of Weeds.—The most effective control of weeds in grassland is secured by careful stocking and judicious manuring, and if these factors are attended to the pasture is unlikely to become foul; drainage, however, is also necessary, and choked drains should be attended to at once. Dwarf weeds, such as daisies and plantains, can be kept in check by manuring, which encourages the grasses and clovers to such an extent that the weeds remain stunted. They can also be very completely killed by certain selective weed-killers (see p. 164). Creeping buttercup can be dealt with by the same means. In both cases there is risk of damage by the weed-killer to the clover, but experiments indicate that, if care is taken in the subsequent management, the clover can be fully re-established. Field thistles should be cut when they are about 6 in. high, and the cutting has to be repeated as frequently as fresh stems appear, so that the plants never flower:

selective weed-killers are also effective, though two successive treatments may be required. Yellow rattle can usually be checked by hard grazing in spring, but also succumbs to cutting early in the season. Land that has been badly managed and is overrun with Yorkshire fog, bent, and brome can hardly be improved without recourse to ploughing and re-seeding.

Bracken is by far much the worst weed in many upland pastures and also on grazings of the lowland-heather type. The most effective treatment, when conditions permit, is to plough the land in June or early July, to disc at intervals during the remainder of the summer, and to re-seed, with the necessary applications of lime and fertilizer, in the following spring. Any fronds that appear among the grass can be broken, while they are still young and brittle, by a heavy roller. Where ploughing is impracticable, recourse must be had to cutting either by hand or machine or to repeated crushing with a type of roller which has longitudinal blades to cut or break the fronds. A single cutting in June is helpful in some cases, but not if the bracken is really strong. Moreover, it has to be repeated for many successive years. Where cutting of the whole area of infestation is impracticable, it is best to concentrate on the outer fringes of the bracken areas so as to prevent their spreading outwards.

Rushes are very troublesome in areas of high rainfall or poor drainage. They may be reduced either by repeated cutting, by very hard grazing in the young stage, or by treatment with selective weed-killer (see p. 164). Ploughing and re-seeding is often ineffective, since the soil of the infested areas usually contains great numbers of buried seeds. Naturally, thorough drainage must be the first step in dealing with rush-infested land, but this must be followed by dressings of fertilizer to encourage the grasses, by careful adjustment of the grazing stock, and by mowing.

Tussock-grass (*Aira cæspitosa*) is also characteristic of wet land; in clay areas where pasture drainage is attained by a ridge-and-furrow layout the weed is usually confined to the furrow bottoms. Tussock-grass generally dies out after drainage, and on the type of land where it is apt to be troublesome mole drainage is often practicable. Scattered tussocks should be dealt with by hand.

Other plants that can become troublesome unless steps are taken to keep them under control are shrubs such as bramble,

briar, whitethorn, and gorse. The former three are most troublesome on the clay pastures of the south. Seedling plants are not sufficiently grown to damage a mower until their third year, so that the easiest preventive is to take hay or to run the mower over the pasture at intervals of two or three years. Gorse bushes burn easily in spring, but are rarely completely killed. Regular mowing, where conditions make this possible, is effective. Sheep graze on the young seedlings in winter.

Ragwort, which is a biennial, is generally troublesome only in the absence of sheep, which usually suppress the small seedlings by close grazing. Since it reproduces only by seed, and since seeds stand little chance of establishing plants in a dense sward, the weed can generally be controlled by liberally manuring the grass, but this is not effective on really poor sandy soil. The "hormone" weed-killers are effective against established plants, but fresh seedlings may appear at intervals. Spear thistle is best controlled by spudding.

Bent-grass and crested dogstail may tend to occupy too large a proportion of the ground, particularly where sheep have long been grazed alone, and may be checked by hard grazing with cattle or mowing for a few seasons. Under-grazing in May and August may lead to an over-development of cocksfoot, which not only becomes coarse but chokes out ryegrass and clover. Whenever a patch of docks appear, the plants should be dug out or they will spread rapidly by seeding.

CHAPTER IX

FODDER CONSERVATION

GRASSLAND herbage, as well as certain other leafy forages (lucerne, vetches, peas, unripe cereals, etc.), can be conserved by any one of three processes.

Haymaking depends on natural drying, the process being speeded up by swath turning, if necessary by tedding and, in certain cases, by the use of tripods or racks. The American process of barn-curing relies for the final stage on an induced current of air.

The terms *grass drying* and *green-crop drying* imply the use of artificial heat for the removal of the whole or the greater part of the moisture—*i.e.* the material may be taken to the dryer either immediately from the forage harvester or the newly-cut swath, or, alternatively, it may be partially wilted in the field. Certain materials which cannot be made into hay—kale and beet tops—may be shredded and afterwards dried.

The process of *ensilage* may be applied either to freshly mown or to slightly wilted material. It depends on two conditions, viz. (1) the exclusion of air (to prevent moulding and aerobic fermentation) and (2) the development of a lactic-acetic type of fermentation which should proceed to a reaction of about *p*H 4 to 4·5. When this point is reached anaerobic fermentation comes to a standstill, but it should be remembered that moulds will develop if the silage is exposed to the air for more than a few hours. The process is thus analogous to that of pickling food in vinegar. In the case of highly nitrogenous material the lactic-acetic type of fermentation may be encouraged by the addition of readily fermentable carbohydrate, usually in the form of molasses. Alternatively, mineral acid may be added or a preservative such as sulphur dioxide may be used. This process, like artificial drying, can be applied to certain materials that cannot be made into hay—kale, beet tops, cooked potatoes, swill, and wet brewers' or distillers' grain.

In the case of grass and other herbage crops the choice as between the three methods depends in part on the type of product

desired—whether a roughage or a more or less concentrated feeding stuff. The other considerations are (1) the comparative efficiency of the three processes as measured by the percentage loss of nutrients during conservation; (2) the amount of labour involved in processing; (3) the labour required to transport and handle the finished product; (4) the capital cost of the equipment required; and (5) the availability of labour at the time of year when the operation falls to be done—for example, haymaking may clash with the early-potato harvest, and silage-making with sugar-beet singling. The choice will also be influenced by local climatic conditions—haymaking requires fine weather while ensilage does not.

HAY-MAKING

The rate of natural drying of mown herbage depends, in the case of any given material, on the temperature and humidity of the air, the velocity of the wind, and the thickness of the swath—*i.e.* a heavy crop is slower to dry than a light one. The first three factors vary widely from day to day, so that—apart from rewetting by rain or dew—the time required for ordinary materials to dry may vary from two up to about ten days. Again, different plant tissues dry at varying rates—the leaf faster than the stem and ryegrass stems faster than those of cocksfoot or red clover. A further material point is that the rate of drying is not constant; evaporation from the freshly cut swath is fast, and the rate falls progressively as the process goes on. Moreover, apart from the occurrence of dew or rain, dry material reabsorbs moisture from air with a humidity considerably below the dew-point. Humidity ordinarily rises during the night, so that hay which has been fit to cart in the evening may, even in the absence of dew, be too damp the following morning.

Most types of herbage, at the hay stage of maturity, have a moisture-content of the order of 70 to 80 per cent. Even if it were practicable to determine moisture-contents in the field, it would still remain largely a matter of judgment to decide the stage of dryness at which the crop is fit to stack. Young leafy material not only packs more closely than mature stemmy stuff, but contains a higher proportion of easily fermentable constituents; old material consists more largely of lignified cellulose, which is very resistant to organisms. Again, hay that has been weathered in the field, because it will have lost a large proportion of its soluble

carbohydrate, is much less prone to heat in stack than stuff that has been quickly sun-dried. Moisture-content is judged by the "feel," but this may be deceptive unless wisps are twisted in the hands—almost to breaking point—to express moisture from the stems. As a rough indication, hay may be safely baled to a moderate density or be put into pike at a moisture-content of 26 to 28 per cent. and may be put in stack at a figure of 20 to 22 per cent. With practice, the degree of "fitness" can be closely estimated by the feel. It should be borne in mind that the material dries, to a greater or less extent depending on the weather, in the process of collection and stacking.

It will be readily understood that, even under the most favourable conditions, there will be some loss of nutrients in the course of haymaking, and it is well known that, at the worst, the loss may be total—*i.e.* the material may, in the end, be hardly worth feeding. The various causes of loss are as follows:—

1. Breakage of leaf. If hay is roughly handled in the later stages of harvesting, or in the process of collection, the leaves shatter and fall to the ground. Clover and lucerne leaves are much more brittle, when dry, than those of the grasses, and the young grass leaf is more easily broken than that which is moderately mature. In the course of drying, the leaves may become quite fragile while the stems still contain a good deal of moisture. Since leafage is much more nutritious than stem, the loss of nutrients by leaf breakage is proportionately greater than the loss in total weight.

2. Living tissue breathes so that, if the herbage is a long time drying, there is a considerable loss of sugar and starch.

3. Living plant tissue is resistant to attack by the ordinary saprophytic organisms—bacteria and moulds—whereas dead material, in the presence of air and moisture, is more or less rapidly decomposed, the rate depending mainly on the air temperature. Hence rain does little harm if it falls while the swath is still green, but leads to heavy loss, especially in warm weather, if it occurs after the plants are dead.

4. Heavy rain, occurring after the tissues are dead, leaches out soluble carbohydrate.

5. Heating in the stack is due to oxidation, mostly of the soluble carbohydrates. Heating is at first caused mainly by bacterial action, but later on further damage may be done by moulds, especially in loose material or in pikes or small ricks.

In large stacks, owing to the exclusion of air, moulding is unlikely except at points where pressure is low. Heating, however, may continue to the point of spontaneous combustion, the critical temperature being about 120° F. Browned hay—material that has heated but has not moulded—is relished by stock, a fact which accounts for the old belief that a certain degree of heating is desirable. The fact is, of course, that the heat is produced by the oxidation of organic matter, particularly of the more digestible and nutritious constituents.

It will be understood that the loss of nutrients varies over a wide range; but estimates based on the yield, dry-matter content, and composition of standing crops, and the corresponding figures for the stacked hay, indicate that the total loss (starch equivalent and protein equivalent taken together) is rarely less than 30 per cent. and may probably average about 40 per cent. The loss can be reduced by the use of tripods or racks, or by the system known as barn-curing.

Hay is an excellent source of vitamin D, but carotene, the precursor of vitamin A, is largely destroyed by oxidation during sun-drying. The amount remaining in the cured hay may be judged by its colour, since chlorophyll is destroyed by light and drying at about the same rate as carotene. Hence, green hay is a useful source of vitamin A, while bleached or browned hay contains almost none.

In the days of abundant labour and before those of cheap imported feeding stuffs, haymaking was carried out with great care and with very large expenditure of manpower. The swath was gently turned by hand-rake or pitchfork, tedding was done without violence, and the material might be gathered into cocks at evening, to be spread out again the following day after the dew had lifted. As drying proceeded the crop was left by day in hand-cocks, which were later combined into larger cocks or pikes and, after a short interval, the crop was finally stacked. When required for feeding, the stack was cut out in trusses for ease and economy in feeding.

The saving of labour, as it has become increasingly necessary, has been achieved largely by mechanisation, but also, in part, at some sacrifice in the efficiency of conservation. The past century has seen the introduction of the swath turner, the tedder, and the side-delivery rake and of a single machine (see p. 218) which can be set to perform any of the three operations in question.

Equipment for collection includes several types of sweeps, the hay loader, and the buck-rake; while the elevator, the horse or engine-operated fork or the stacker largely eliminates hand-pitching at the stack. Mechanical cocking, though possible, has not been widely adopted, but the hay bogie, the buck-rake, or the rick-lifter enables cocks or pikes to be moved *en bloc* to the rick. Again, baling in the field has become very common in recent years and can be carried out either by a stationary or a pick-up machine. In other countries still other devices are in use: the swath crusher, by bruising the stems of the green plants between rollers, is an aid to quicker drying, and the chaffer-blower not only replaces the elevator but enables the material to be distributed, in a loft or barn, with very little hand labour and at the same time enables much denser packing than can be attained with long material.

The initial processes in haymaking are commonly the same, whatever is to be done later. The crop is mown, preferably at the time when the bulk of the plants are in flower or coming into flower—*i.e.* when the grasses are shedding or beginning to shed their pollen. At this stage the total amount of digestible nutrients reaches a maximum because, although the weight of dry matter might continue to increase subsequently, digestibility would be reduced through the lignification of cellulose. The crop is commonly left in the swath until the upper side is dry, when the swath is inverted to expose what has been underneath. If the weather is favourable, the moisture-content may have fallen to 25 or 30 per cent. in two or three days from cutting, when the crop will be ready for windrowing.

If light rain should fall—enough to wet the bulk of the swath but not to compress it—the position may be met by letting the top side dry and then turning the swath back. If, on the other hand, the swath has been beaten down and is sodden, it will be necessary to use the tedder. Tedding will, however, inevitably cause some loss of leaf, which loss will be high if, as often happens, the upper side of the swath is already dry when the operation is carried out.

The only modifications of this procedure that have been suggested by recent experimental work are, firstly, the crushing of the swath between rollers immediately after cutting. The crusher may either operate on the swath as it leaves the cutter-bar or it may pick up and crush that cut on the previous round.

The crusher is attached to the mower and is operated from the power-take-off. Second is the tedding of the freshly cut swath either by an attachment behind the cutter-bar of the mower or by a standard tedder. It is the common belief, probably well founded, that tedded material is more completely wetted by light rain than that which is lying in an undisturbed swath; but experiments have shown that in the absence of rain "green tedding" greatly speeds up the rate of drying. Moreover, the tedder causes very little damage to the plants while these are still sappy.

From the stage indicated above, the simplest procedure is to run the crop into windrows—two or three swaths together—by means of a side-delivery rake, and later, when drying has proceeded to the necessary stage, to stack. Where the stack is to be built in the field a hay-sweep conveys loads to the foot of the elevator, on to which the hay is pitched by hand-fork. A gang of five men—one sweeping, two pitching, and two building—may put together up to 20 tons per day. The field is finally raked over and the rakings swept to the stack.

If the hayrick is to be on another site, or if the crop is to be stored in a barn at the homestead, wagons or trailers must generally be used. The buck-rake may indeed be preferred for short hauls—up to a quarter or a third of a mile—if the going is level. On rough land spillage is large and, in any case, the individual loads are too small for full economy if the haul is more than, say, a third of a mile.

Stacking from the windrow gives tolerably good results with grassy material cut at a relatively mature growth-stage. Indeed, it is doubtful whether such second-rate raw material justifies any more expensive process. But with young leafy growth, especially if it contains a high proportion of clover, the system leaves much to be desired. Such material must be very fully cured if heating in the stack is to be avoided and, since it cures slowly, it must be left on the ground, at serious risk, for an undesirably long time. These facts suggest that the making of high-quality hay necessitates an intermediate stage between the windrow and the stack.

In arable districts where the farm staff is large in relation to the acreage of hay, and especially where there is no great pressure of other work at hay-time, more pains can be taken to ensure a first-quality product. Such conditions obtain in north-eastern

Scotland, and the traditional system of that area may be described.

In most seasons the crop can be cut at the near-optimum time, just because the acreage is small in relation to the labour resources. As soon as it has been mown, or after it has been windrowed, large wooden tripods or "bosses" (later to be used for corn stacks) are distributed over the field—two, three, or four per acre according to the size of the crop. When the hay is considered fit it is swept (either from swath or windrow) to the tripods, and is built by hand-fork round the tripod to form a tall and narrow pike, being lightly tramped in the process. The pike is raked down so that rain may readily run off, special care being taken in finishing off the "roof." In windy areas ropes of esparto or twisted hay are used to secure the top. A horse-rake follows the cockers to clean up. The pikes are commonly left standing for about three weeks, and take little harm even if stacking has to be postponed till after the corn harvest. But the tripods are ordinarily required again at that time. The pikes are ordinarily built to a size containing 12 to 14 cwt. of mature hay.

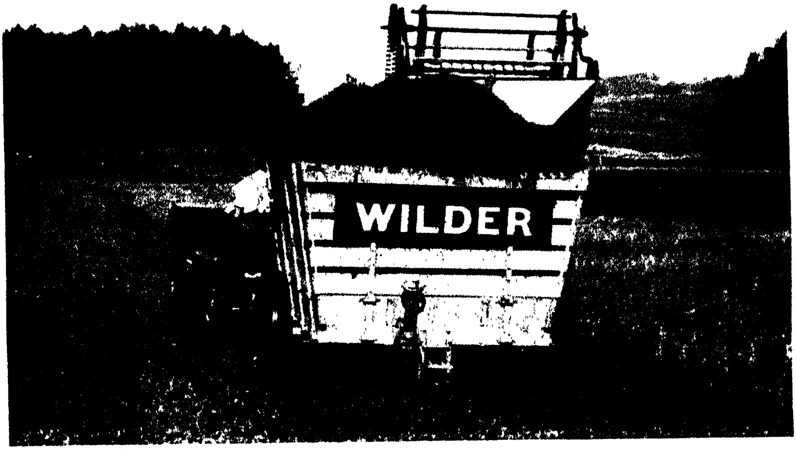
An objection to the wooden tripod is that its presence in the pike precludes the use of the hay-bogie or buck-rake, by whose means a pike may be conveyed bodily to the stack, or of the rick-lifter, by which it may be loaded bodily on to a haycart or trailer. But if the tripod is omitted the pikes must be kept rather smaller and, since the unsupported material settles down to a more compact mass, the crop must be drier than it need be if the tripod is used.

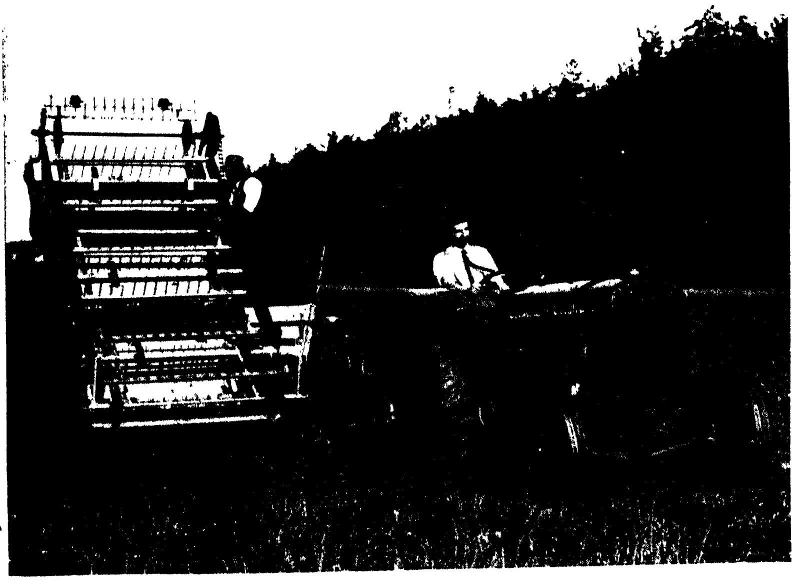
One modification of the method is to use a collapsible steel tripod, which is not only lighter and easier to handle but can be more widely spread so as to carry more of the weight of the rick and whose presence does not preclude the use of the hay-bogie or buck-rake. Moreover, the tripod is combined with a triangular cage, which is used to provide a vent connecting the central cavity of the rick with the outside air, thus promoting an upward and outward movement of air through the material. The bulk of hay is ordinarily about half what is built round the tall wooden tripod previously described. The effect of the modifications is to enable the grass to be cocked, while still very green, without risk of heating or moulding. Hence the loss, both of major nutrients and of carotene, is reduced. Moreover, the crop may be efficiently cured even if it is cut before the normal "hay stage"

of maturity, *i.e.* while its nutritive quality is still relatively high; the finished material is intermediate in quality, between good ordinary hay and average dried grass. The system is obviously laborious and is of doubtful profitableness where the original material is of poor botanical composition or is over-mature. Moreover, the capital cost of the metal tripods is considerable.

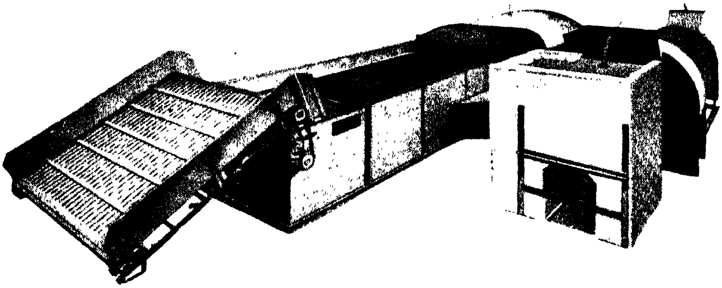
With a view to reducing capital charges the metal tripod may be replaced by a pair of V-shaped wooden hurdles which can be interlocked to form a four-legged pyramid. Each hurdle is built of four pieces of timber. The two legs are 7 ft. long and of 2 by 2 in. section. The frame is fixed together, with the lower ends of the legs about 5 ft. apart, by means of two cross-pieces of about 3 ft. 4 in. and 5 ft. in length respectively, the cross-members projecting about a foot on either side of the legs. The two hurdles are put together in the form of a square-based pyramid by leaning them together, with the top of the one resting on the upper cross-piece of the other and projecting through it. The framework so contrived will carry enough material to make 3½ to 4 cwt. of fully dried hay.

The crop being mown at the early hay stage—*i.e.* at the commencement of flowering—may, in good weather, be turned the day after it has been mown and put up on tripods the next again, but experience is necessary in forming a judgment about the stage at which this may be safely done. "Three-parts cured" is a phrase commonly used in this connection, and this may imply a remaining moisture-content of about 35 per cent. The cock must be put together in small forkfuls, and when finished the whole weight should be carried on the frame—*i.e.* the hay will be touching but not resting on the ground. The finished cock should be about 9 ft. high, with a dome-shaped top and with the outside raked straight so as to shed rain. Two men, working together, with the material swept to them, may cock at a rate equivalent to about 2½ tons of cured hay per day. The labour cost of cocking will thus be about 15s. a ton, a figure that will be fully justified if a really high-quality product is obtained. The capital cost of the frames may vary from 6s. to 12s. per pair, equivalent to 30s. to 60s. per ton of hay made. Labour in the subsequent stacking can be economized by lifting and transporting the pikes by means of a buck-rake, with two tines removed in order that the driver may avoid striking the legs of the structure in pushing under the cock.

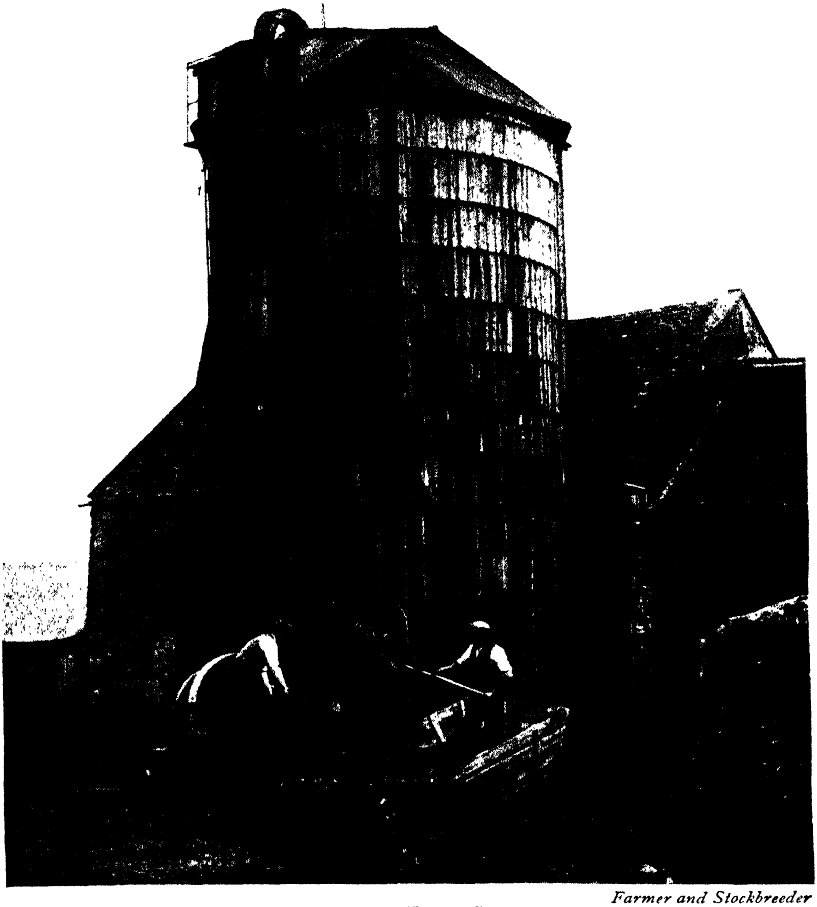




"CUTLIFT" MACHINE AT WORK ON SHORT GRASS—REAR AND FRONT VIEWS



OUS FLOW DRIER FOR GRASS (RANSOMES)



Farmer and Stockbreeder

FILLING A TOWER SILO

A good deal of experimental work has been done in this country on barn-curing, but so far the system has not been widely adopted. Barn-curing is fairly common in the United States, but experience there is no very sure guide, since air humidities in America at the hay season are, upon the whole, a good deal lower than those that prevail over the greater part of Britain, and high air humidities necessitate the use of relatively large amounts of fuel.

The necessary installation consists of a fan, with electrical or other appliance for heating the delivered air, and a series of ducts in the floor of a Dutch barn or other suitable building. In some of the early experiments unheated air was used, but it appeared that in Britain air humidities at night, and sometimes also by day, are so near saturation point that the rate of drying may drop almost to zero. Indeed, material that is nearly dry may pick up moisture from cold air. A 4- or 5-ft. layer of wilted material is evenly spread out, in the loosest possible condition, on the floor of the shed, air is blown through, and as each layer is sufficiently dried another is added. Cold air may be used at times when the relative humidity of the air is low; otherwise, and normally during the night, the air must be heated. Consumption of power for heating will ordinarily, of course, be highest in the most humid parts of the country, where hay-making by natural drying is most difficult and precarious.

By much the most striking development of recent years has been the rapid development of baling in the field. Farmers who formerly owned stationary balers generally continue to use these, the hay being brought to the baling site by sweep and fed into the machine by hand-fork. Otherwise the preference is for the pick-up machine, which gathers the material from the windrow and either delivers the bales, singly or in batches, on to the ground or else passes them to an attached trailer. The same machine is used during grain harvest for collecting straw after the combine harvester. Machines are available to produce either rectangular or cylindrical bales; the latter are ordinarily string-tied, while the former may be bound either with string or wire. Some of the earlier types of wire-using machines require workers to insert the wires by hand, but modern types are fully automatic. The density of the bale can be regulated on all types.

The obvious advantages of field baling are economy of labour, reduction of waste—both in the making and in the subsequent

handling of the hay—and the opportunity provided of getting the material into a fairly safe form while it is still too green to be safely stacked.

As is true for other systems, the stage of dryness at which the hay can safely be baled can be learnt only by experience, the safety point varying with its botanical composition, the stage of maturity at mowing, the size and density of the bale, and the weather outlook. In general, however, it may be said that hay may be baled before it would be fit to build into a large rick, must be considerably drier than it need be for cocking on tripods, and be more or less at the same stage as is normal for putting up in the Scottish type of pike.

If the bales are to be built up into a large stack, or stowed in large bulk under cover, they must generally be left in the field to dry out for a few days. If, on the other hand, they are to be distributed over a number of sites, a few tons here and a few there, carting can proceed sooner, each successive layer in each stack or store being given a day or two to dry before another is added. If bales are left in the field they should either be placed up on end or set up in piles of five so as to expose a large surface to the air and a small one to rain.

GREEN-CROP DRYING

The physical principles of crop-drying are discussed, and the various types of available equipment are described in Chapter VII of Part I.

While some types of small tray driers, especially if oil-fuelled, can be used intermittently—*e.g.* to dry a few loads of grass between milking times—drying upon any considerable scale must be as nearly as possible a continuous process if the expensive installation is to return a profit. Continuous operation, of course, implies a special full-time staff, working preferably (from the point of view of securing full output from the machine) in two or three shifts. The procurement of the necessary number of workers, and their housing, may be very difficult. But the main problem is to provide a regular supply of material, at the right stage of growth, throughout the longest possible period of the year. This, in turn, necessitates skilful and resourceful management of the grassland, supplemented often by arable crops.

Drying will be likely to prove uneconomic if any considerable

proportion of the product is of second- or third-rate quality, and, assuming that the drying is properly done, quality will depend largely on the growth stage of the grass. This is highest in the young stage and deteriorates very rapidly as the plants approach and pass the heading stage. The following figures (nutrient-content per 100 lb. dry matter) illustrate the point :—

Growth stage	Starch Equivalent	Protein Equivalent
1. Young leafy	60	16·0
2. Leafy	59	12·0
3. Ear emergence	57	9·0
4. Flowering	52	6·5
5. Seed-setting	50	4·8

It should be borne in mind that material at stage 3 can be efficiently conserved by ensilage and that at stages 4 or 5 by some system of haymaking, which processes are very cheap by comparison with artificial drying. Even tripod curing of hay, which is fairly laborious, can be done at a cost of £3 or £4 a ton, while drying costs might, for the same material, run from £12 to £16.

In order to secure the required steady and long-continued supply of young material it is necessary to have a series of swards of differing botanical composition. The commoner types of grassland plants are classified, in respect of earliness, as follows :—

Very Early: Italian and New Zealand short-rotation ryegrasses.

Early: S. 24, Irish, and New Zealand perennial ryegrasses.

Medium: S. 23 and Kentish indigenous ryegrasses.
S. 26 and S. 143 cocksfoot.
S. 53 meadow fescue.
S. 48, S. 51, and Scotch timothy.
Broad red clover.

Late: Lucerne.
Late-flowering red clover.
White clover.

Very Late: Average old pasture (*Agrostis*, ryegrass, white clover).

It is, however, rarely necessary to have swards of five different degrees of earliness. Needs may usually be met by three, with perhaps a reserve of old grass to fill the gap in supplies which may occur, in a cold dry spring, between the first and second rounds of cutting. Thus one field might be under Italian or short-rotation ryegrass; a second under S. 24 ryegrass or S. 37 cocksfoot, with S. 100 clover in either case; and a third of S. 53 fescue, S. 48 timothy, and S. 100 white clover. It is generally inadvisable to mix cocksfoot with another grass, since the thick leaf-bases of the plant are slow-drying.

Such a scheme assumes that lucerne cannot be grown successfully. But lucerne should be brought into the scheme wherever possible, since it has the advantage, shared with the clovers, that its protein-content falls with increasing age much more slowly and less markedly than that of any grass; moreover, its growth is well maintained during dry spells. In some cases lucerne is the major crop, being supplemented only with a relatively small area under Italian or short-rotation ryegrass, to make provision for an early start in spring, and to extend the period of operation after mid-September.

Apart from the use of plants of differing degrees of earliness, the supply of material may be smoothed out by the skilful timing and quantitative regulation of nitrogen applications and also by thought in the allocation of the various seeds mixtures between the several fields—early types on the early land and late types on the colder ground. If, for example, Italian ryegrass is sown on light, warm soil and receives its nitrogen top dressing in early February, and if S. 37 cocksfoot is sown on heavier land and is top-dressed in late March, a sufficiently wide spread of supplies should be assured.

Whenever, despite all care in planning, the dryer fails to keep pace with the growth of the herbage, the best course is to mow an area for silage. To leave it for hay will generally throw the whole programme out of gear.

A full and quick response of the herbage to nitrogen depends upon an adequate supply of other nutrients, and it must be remembered that the drain upon these, under a grass-drying régime, is very high. Allowing for inevitable losses (in particular phosphate fixation) and assuming a yield of 2½ tons of dried material in the season, the fertilizer programme might be made up of annual (autumn) dressings of about 5 cwt. superphosphate

and 3 cwt. muriate of potash per acre, with about 3 cwt. of sulphate of ammonia in early spring and 2 cwt. Nitro-chalk after each cut, excepting only the last of the season. Some prefer to use a compound fertilizer in early spring in place of the autumn application of minerals and the spring application of nitrogen. Further points are that the quantities of nitrogen applied in summer should be related to the proportion of clover in the sward, and that the rate of depletion of the lime reserves of the soil will depend upon the quantity of ammonium sulphate that is used.

Fields for grass-drying must be closely grazed in autumn, and maiden seeds should be repeatedly chain-harrowed to break down the stubble of the nurse crop. The presence of any considerable amount of dead herbage, or of straw, in the first cut will have a very deleterious effect on the quality of the product.

Arable crops and catch crops may often be used to advantage to supplement the produce from long-duration leys. Thus a catch crop of rye or of Italian ryegrass sown in July (*e.g.* after early potatoes) should yield both a late autumn and an early spring cut, and sown later, may yield a cut, or even two, before the land is wanted for roots or kale. Where lucerne cannot be grown, a late sowing of oats and vetches will give a good crop at a time when other material is scarce.

It would obviously be useful, in securing fuller employment of the drying plant, if kale could be used during the period from October till December. The one difficulty is that kale must be shredded as a preliminary to drying; the other is the high moisture-content of the material. It might appear that the difference between, say, 80 per cent. of moisture in grass and 86 per cent. in kale is not very extreme; but a calculation will show that, for every ton of dry matter produced, the amount of water to be evaporated will be 4 tons in the first case and over 6 tons in the latter. The position is worsened by the fact that kale, in the late autumn, often carries a considerable load of superficial water.

Sugar-beet or fodder-beet tops, in slightly wilted condition and externally dry, may have a moisture-content of the same order as that of young grass. If they can be secured in reasonably clean condition they will, after shredding, provide useful material for the dryer. Where washing is necessary in order to remove dirt, the moisture-content of the mass, and hence the cost of drying, will be greatly increased.

To return to grass, it has already been said that the nutritive quality of the product is related to the age of the plant tissues rather than to the height of the crop. At the one extreme Italian ryegrass, in a growthy spring, may reach a height of a foot or more before there has been any serious decline in nutritive value; at the other extreme a low-growing species like S. 23 ryegrass, growing slowly in a period of summer drought, may have to be cut at a height of 4 or 5 in. if a first-quality product is to be obtained. These circumstances raise a problem in the choice of harvesting machinery. Fairly long material can be mown and left some little time in the swath—perhaps cut one afternoon and picked up the next. In this case the equipment needed would be a mower and a side-rake (which are normal parts of the farm equipment) and a green-crop loader. By contrast, if very short material is once allowed to fall to the ground there will be heavy loss in its subsequent collection. Hence the cut-lift type of machine (see p. 202) must be used, and there can be no wilting.

Wilting in the field, at best, results in some loss of carotene, but this is of little consequence if the product is to constitute a considerable part of the ration; it will be important if the product is required mainly as a source of vitamin A. Wilting has the obvious advantage of saving fuel and other drying costs, which depend largely on the moisture-content of the raw material. With fresh material at 80 per cent. moisture 4 tons of water must be evaporated per ton of product, while with wilted material, at 65 per cent. moisture, the figure falls to 1·9 tons.

Another point of importance in relation to costs is that, apart from surface moisture in the form of dew or rain, the dry-matter content of growing herbage fluctuates from hour to hour, being ordinarily at a minimum in the afternoon. The same thing happens with grass lying in swath. Hence there is a case for collecting a twenty-four hours' supply between, say, midday and 4 o'clock. But even if it is spread out fairly thinly, the green material will rarely keep cool for more than twenty-four hours. Hence no more should be brought in than can be dried by the afternoon of the following day.

The number of cuts to be made in a season will, of course, vary with seasonal conditions, but must be decided with some reference to the quality of product desired. With five or six cuts—*i.e.* at intervals of four or five weeks—the product will be of high quality, but the yield will be relatively small. This is because

frequent defoliation will reduce photo-synthesis. Moreover, the cost of harvesting per ton will be high. Three cuts in the season will usually give the highest yield of starch-equivalent per acre, but the product will hardly deserve the name of a concentrate.

Sometimes a sward is grazed for part of the year or, more frequently, used to provide a silage crop, and is also cut for drying—perhaps twice—during the season. If grazed, the mower should be run over the field to remove ungrazed tufts or stemmy material, and the land should then be chain-harrowed to level the surface and spread droppings. Grazing should generally be avoided where the cut-lift is to be used subsequently, since this machine, with its cutter-bar shaving the ground, requires a very smooth surface and will be very apt to collect any remaining dung.

With land of fair average quality under average rainfall, with a fertilizer application of the amount suggested above, and with four cuts in the season, the total yield of dried grass will ordinarily be between 2 and 3 tons per acre. In the areas of high rainfall, with more intensive fertilization, yields of 4 tons per acre are not unusual, and 5-ton yields have occasionally been recorded.

With respect to the necessary degree of drying, it is well to let the process proceed until the moisture-content of the grass has fallen to 2 or 3 per cent. It is true that the material would keep in store at a moisture-content of 10 or even 12 per cent.; indeed, it will ordinarily pick up this amount under farm storage conditions. But even with careful work it is difficult, even in material with 6 or 7 per cent. moisture, to ensure the complete absence of damp pockets, which may heat up. Many fires have resulted from this cause. Even if drying has proceeded to the 3 per cent. point, it is a wise precaution to delay bulk storage for a few days.

The form of the finished material, for convenience in storage and handling, is another matter of some importance. Longish material will hold together fairly well in a bale, and bales are subject to less wastage than loose material. Short material cannot be made into durable bales, and it is now normal practice to put the material through a hammer mill and pack the meal in paper bags. Paper is preferable to textiles, since it is less permeable to air and therefore gives better protection against the loss of carotene. Many of the larger drying plants process the milled grass into "nuts" and in some cases incorporate

cereal meals in order to get a product with the desired protein-carbohydrate balance for a particular purpose—*e.g.* a production ration for dairy cows.

ENSILAGE

It has long been known that watery material such as wet brewery grains, distillery paste, and wet sugar-beet pulp could be satisfactorily preserved by close packing in pits or clamps. The possibility of ensiling grass and other greenstuff was explored in this country during the eighties of last century, but only a few farmers—mostly those whose circumstances rendered hay-making very difficult—were induced to take up the process. The early workers appear to have favoured the production of "sweet" silage, using material at the hay stage of maturity and deliberately encouraging a hot fermentation. It is true that high-temperature fermentation yields a product of pleasant aroma and high palatability; but the fermentation is associated with heavy losses through the destruction of digestible carbohydrate and the marked depression of the digestibility of the proteins.

The first widespread development of ensilage took place in the United States, the object being to provide a substitute for mangolds and other roots. The crop commonly ensiled was maize which, under American conditions, is much more reliable than roots and also makes much smaller demands on hand labour; moreover, maize, at the appropriate growth stage, is, by reason of its high content of starch and sugar, a very suitable material for ensilage. The normal equipment used was a chaffer-blower and a tall cylindrical silo, the walls being made as smooth as possible in order to facilitate compression. The general experience favoured a height of 40 or 50 ft., so that the contents would be compressed largely by their own weight—*i.e.* with a minimum of treading.

In the early twenties a considerable number of American-type silos were erected in Britain, mostly on clay-land stock farms where the cost of root-growing had become prohibitive. The favoured material for ensiling was a cereal-legume mixture—ordinarily oats with beans, peas, or vetches, or sometimes all three. The crop was cut at a relatively advanced stage of growth—the cereal "in the milk" and the legumes well podded—and a useful product was obtained. The main obstacle to the general adoption of the system was the high cost of the necessary

equipment—the silo itself, the chaffer-blower, and the power unit required to drive the latter.

In the thirties the A.I.V. system was introduced from Finland. This was commonly applied to grassland herbage, mown at a fairly early stage of growth and packed, without chaffing, into relatively small and cheap cylindrical silos of wood, concrete, or steel. The A.I.V. system depends upon the addition of enough mineral acid (hydrochloric and sulphuric) to establish from the outset a degree of acidity (*p*H 3 to 4) at which bacterial action is almost completely inhibited. The surface was commonly sprayed with a special material to prevent the development of moulds. In general, conservation was found to be efficient, but the process of filling the silo was laborious, the handling of strong acid was unpopular with workers, and it was necessary, when the silage was fed, to neutralize the contained acid by adding ground chalk.

During the Second World War, as an emergency measure, large numbers of small tower silos were erected and were commonly filled with grass. These served a useful purpose during the period of emergency, but the system was generally regarded as too laborious for use under normal conditions.

The pit or clamp systems are now those most widely used, though some farmers still prefer the silage stack. The pit and clamp have the double advantage that, in filling, the loads can be dumped directly where they are to lie, and that the necessary degree of compression can be secured by carting over the mass during the process of filling and, after filling, by driving a tractor to and fro over the top. In some cases it is well to add molasses in order to promote the required type of fermentation.

In Britain the commonest material for ensilage is grassland herbage, either from leys or old swards and preferably cut at the stage when the grasses are coming into ear. Younger material may be used if a high-protein feed is required, but short grass is difficult to collect with ordinary farm equipment—*i.e.* a cut-lift type of machine is required. In seasons when hay-making is brought to a standstill by wet weather the crop may be salvaged by ensilage, but stuff that has reached or passed the hay stage of maturity, especially if it has suffered weathering in swath or windrow, can obviously yield a product of only very low food value.

Lucerne, *sainfoin*, and *red clover* can be made into excellent silage, though the material must either be wilted or treated with

molasses if a good fermentation is to be secured, the point being that the legumes have a high protein-content in relation to that of sugar and are therefore prone to undergo cold (butyric) fermentation. Among arable crops the most useful are mixtures of *oats and peas*, *oats and vetches*, or *oats*, *beans*, *and vetches*. These have the advantage that they can yield a good product over a fairly wide range of growth stages. Moreover, they can be more easily built than grass into a stable silage-stack. *Maize*, as already said, is a very suitable plant for ensilage and in many countries provides the main supply. Varieties are available that, in the south-eastern half of England, attain the proper silage stage (grain well formed but leaves still green) by September. The later-maturing types which have sometimes been used are still so immature at summer's end that they are subject to heavy loss of sugar through the drainage of juice. *Marrowstem kale* has too high a moisture-content for the best results, losses by drainage being high. Moreover, it is impracticable to secure much wilting at the season when the crop is harvested, and chaffing is necessary. Otherwise the crop is very easy to ensile, because it does not readily heat even in a loose mass. All that is necessary is to blow the chaffed kale into a heap, preferably in a corner between two high walls, and provide some rough protection from rain. *Sugar-beet tops*, if they can be collected in reasonably clean condition, yield a useful silage and being "cold" by nature need little consolidation. Indeed, they are very suitable for stacking. *Green pea-haulm* from crops grown for vining is excellent material.

The general principles of ensilage have been outlined at the beginning of this chapter, but the process must be adapted to the nature of the raw material. The object is to ensure a predominance of the lactic-acetic type of fermentation, which is favoured by a moderate degree of aeration at a temperature of about 100° F. Lower temperatures, resulting from a shortage of fermentable carbohydrate or from the over-compression of sappy material, or both, favour butyric fermentation. Butyric acid is a foul-smelling substance which not only reduces the palatability of the silage but imparts a taint to milk and dairy products. Moreover, the objectionable and very persistent smell is complained of by workers and their families. The safeguards against butyric fermentation are partial wilting of the material in the field, slow filling with light compression, and the use of molasses.

At the other extreme silage that has seriously overheated (over 120° F.) and is characterized by a dark-brown colour and sweet (caramel) smell will not only have lost an excessive amount of digestible carbohydrate but will show a very low figure for the digestibility of its protein. Hence relatively mature material, with a high proportion of grass or cereal, should not be wilted, should be ensiled quickly, and heavily compressed.

A good general plan is to put 2 or 3 ft. of material into the silo, with only light packing, and to allow the temperature to rise to about 100° F. before superimposing further material. This will ordinarily happen in about two days. Thereafter the amount of compression should be regulated according to the temperature of the mass. Good control requires the use of a thermometer which can be inserted at any desired depth, and which therefore should be fitted into a spear.

Pit and Clamp Silage.—In making a pit silo, or in the siting and building of a clamp or stack, four requirements must be met. The first is drainage. Water-logging of the lower layers, whether by the accumulation of plant sap or the inflow of surface water or a rise of the water table in winter, will result in butyric fermentation. Hence the site should be high in relation to the surrounding ground and, unless the soil is freely permeable, drains should be laid along each side of the base and be provided with a suitable outlet. Unless there is a firm and permeable bottom a 6-in. layer of hard-core or gravel should be laid.

Second, the layout should permit consolidation with a minimum of labour. The least laborious method is to run a tractor over the mass both in the process of filling and after this has been completed. Again, it should be noted that the mass will shrink, horizontally as well as vertically, as fermentation proceeds. Hence if the walls of a pit, or the side walls of a clamp, were to be vertical, air would gain access at the sides, and spoilage would result. The walls should therefore slope outwards, with an inclination of about 1 in 4; for instance, if the walls are 4 ft. high or the pit is 4 ft. deep, the width should be 2 ft. greater at the top than at the bottom. The material, as it sinks, will then wedge itself tightly between the walls. In order to secure good settlement the walls should be smooth.

Thirdly, since exposure to air causes waste by rotting, the surface exposed should be as small as possible. Obviously, other things being equal, wastage will be higher in small than

in large silos, but other considerations are involved—*e.g.* two lots of material, becoming available at different times, should be ensiled separately rather than in one silo. The occurrence of outside wastage is obviously an argument for a pit or a walled clamp rather than a stack.

Fourthly, in all but the driest areas the silo should either be roofed over or should be domed up and thatched so as to shed rainwater.

From the point of view of labour-saving, an excavated pit, rectangular in plan and about 5 yds. wide, open at both ends and with a gentle incline at each, has obvious advantages. Where this is to be used over a period of years it is well worth while to have the sides faced with concrete. Where a pit would be subject to water-logging it is well to keep the silo above ground, when it may consist simply of two parallel side walls composed of concrete slabs with a smooth inner surface and sufficiently strong, well supported, and deeply grounded to withstand the heavy pressure that develops during and after filling.

The siting of the silo depends on a balance of considerations. If, on the one hand, it can be adjacent to the fields on which the material is grown, the cost of collection and filling can be kept at a low figure by the use of the buck-rake; but if this would imply a considerable distance between the silo and the winter quarters of the stock, then a good deal of winter labour will be involved. In any case, except when the land is light, firm and well drained, the silo should be adjacent to a hard road. Ideally, the silo should be in the field that has grown the crop and in which the silage can be fed in winter.

Another question is whether or not the crop should be slightly wilted in the field. American work suggests that a satisfactory fermentation is ensured without the use of molasses if typical grassland herbage, at the proper stage of maturity, is wilted to a moisture-content of about 65. In drying weather this stage might be attained by mowing in the early morning and carting in the afternoon; in ordinary weather it would be attained by cutting one day and carrying the next. But such a procedure is practicable only with grass which is long enough to enable it to be cleanly picked up after wilting, by which time it may have passed the stage of maturity to give a high-grade product.

The need to use molasses depends on the nature of the material. Kale, beet-tops, oat-and-legume mixtures at a fairly advanced

stage of growth, and also relatively mature grass that has been wilted in the field will, if well managed, develop a good type of fermentation without assistance. Young grassy and especially young clovery herbage are apt to go wrong unless molasses is used. Two gallons of molasses per ton of greenstuff is a usual allowance. The molasses should be diluted with twice its volume of water and sprayed on to each successive layer by means of a watering-can with a large-aperture rose.

The silo must be kept under observation for a week or two after filling has been completed, the temperature being taken at intervals of a day or two. Should the temperature rise much above 100° F. further pressure should be applied by tractor or by leading about a pair of horses. If the inclines permit, a heavy ring-roller may be used.

Use of Preservatives.—Various materials, in addition to mineral acids, have been tried as silage preservatives. Sulphur dioxide injected into the mass proved to be useful, but efficient application (from pressure cylinders) proved to be difficult. At the time of writing it appeared that the most promising material was a complex of acid sodium phosphate and acid sodium sulphate. This substance has the effect of a medium strong acid and, when applied at a rate of 1 to 2 per cent. of the bulk, effects a rapid reduction of the H to a figure of 4·2 to 4·5.

Apart from preservatives in the narrower sense, various materials may be added to the green-stuff. Thus maize or other cereal meal provides readily fermentable carbohydrate, and dried sugar beet pulp absorbs surplus moisture and reduces drainage.

Stack Silage.—Ensilage may be carried out by building the green herbage into a stack, with a top layer of heavy material to give the required compression. One alternative is to add an upper storey of baled hay or baled straw, and another is to rely on a layer of soil with the addition of large stones if these happen to be at hand.

The exposed surface being much larger than that in pitted or clamped material, the amount of wastage tends to be relatively high. From the point of view of minimizing losses, it will be obvious that large stacks are better than small and that a round shape is preferable to a square or any other form of rectangle. The system works best with longish material, since a stack of short grass is apt to settle unevenly, and may slip or even fall

over. Props cannot be used to promote even settlement without reducing the degree of consolidation. It is scarcely practicable to get even consolidation throughout the mass—indeed, it is rather a common fault in stack silage that the lowest layer goes sour while the upper overheats. In order to avoid such trouble the lower part of the stack should consist of wilted herbage, and the upper zone of fresh or even fairly wet material.

Building is started by dumping loads from a sweep or buck-rake to a depth of 3 or 4 ft., from which point an elevator or horse-fork must be used if the great labour of hand-pitching is to be avoided. A total height of about 15 ft. before settlement is commonly aimed at. The sides should be kept as nearly vertical as possible and should be well plucked or trimmed as building proceeds, the trimmings being put on top. The stack must be kept "well hearted up" during its construction in order to produce a structure like a pile of inverted saucers. If the centre is allowed to get hollow, rain will penetrate and cause damage. As said, the top layer of herbage should be rather wet, but a further layer of useless stuff, *e.g.* hedge-side mowings or stack-bottom waste, should be added for protection before the soil or other weighty material is superimposed.

The Feeding of Silage.—Well-made and fully settled silage commonly weighs between 10 and 12 cwt. to the cubic yard, and dry-matter contents range from about 20 to about 28 per cent. It is thus not very difficult to cut out the desired daily ration with reasonable accuracy. A tolerably close estimate of feeding value can be based on the dry-matter and crude-protein contents, both the protein equivalent and starch equivalent of the dry matter being closely correlated with total protein. The exception is in the case of overheated material, which invariably has a lower feeding value than would be calculated on such a basis. Silage with 15 per cent. or more crude protein in the dry-matter is usually designated high-grade; that with less than 12 per cent. is classed as low-grade.

Fodder Conservation Policy.—There are few farms on which any single method of conservation should be applied to the whole of the available material. Most farms can make good use of a considerable quantity of ordinary hay—*e.g.* for dry cows, in-calf heifers, and the older classes of store cattle. Young calves and deep-milking cows, however, should have more nutritious dry fodder, *e.g.* tripod hay from early cut grass. Again, the

partial substitution of silage for ordinary hay will enable a considerable saving of concentrates, while high-quality dried grass can well replace a large proportion of the high-protein concentrates in the case of ruminants, and a smaller but still considerable proportion in that of pigs and poultry.

Other advantages of a well-conceived programme may be the avoidance of labour peaks and improved sward control; for example, grassland that is mown at the silage stage will ordinarily produce a better aftermath than that which is mown at the hay stage and will provide grazing at what is otherwise apt to be a period of shortage. Finally, if the total acreage to be conserved is high in relation to the available labour, and if the attempt is made to turn the whole of the produce into hay, much of the crop, in many seasons, will have passed the optimum growth-stage, for any process, before the work can be completed.

Miscellaneous Silages.—As already said, wet beet pulp and wet brewery grains keep well in pits without the necessity to add molasses or other preservatives. Such materials compress well under their own weight. Spoilage by moulds may be largely prevented by covering up with old sacks and adding a few inches of soil. Surplus potatoes can be very efficiently conserved by placing them in a metal bin or small concrete silo with a pipe at the bottom through which steam can be blown under pressure. Alternatively the potatoes can be cooked in batches—*e.g.* in an ordinary farm steaming outfit—and packed, while still hot, into a permanent container. Filling should be done rapidly so as to minimize infection by mould spores. The top should be covered with straw or old sacking and sealed over with soil.

An alternative method, applicable where old potatoes are still on hand at the time when green herbage becomes available, is to ensile uncooked potatoes along with grass. The tubers should be de-sprouted, since the sprouts contain a poisonous substance. The potatoes are ensiled with about double their weight of short grass, and the two materials are filled as alternate layers. The desirable fermentation temperature in this case is relatively high, probably about 120° F. Hence the pressure applied should be relatively light.

Future Developments.—At the time of writing two promising developments, both aiming at labour economy in feeding, were the baling of the material by a pick-up machine and the self-feeding of cattle from clamped silage.

PART III

FARM LIVE STOCK

CHAPTER I

GENETICS: ANIMAL BREEDING

ANIMAL REPRODUCTION

IN animal reproduction the embryo develops from a fertilized egg, which is the product of the fusion of an egg cell produced by the female with a sperm cell produced by the male. In some species the fertilized egg divides, giving rise to two or more embryos, and one-egg or so-called " identical " twins occur occasionally in cattle, though not in other domesticated animals. A large majority of twins in cattle are "ordinary" or two-egg twins.

The primary sexual organs of the female are the ovaries, and the shedding of the egg from the ovary may be taken as the start of the reproductive process. The ovary, apart from producing eggs, gives rise to internal secretions which control the œstrous cycle. At or about the time of shedding of the egg occurs the period of œstrus (" season " or " heat ") when mating takes place. The ruptured follicle, from which the egg has been shed, forms the " yellow body " (*corpus luteum*), and so long as this persists œstrus does not recur. Normally, however, in the non-pregnant animal, the yellow body disappears after a fairly definite period of time, when another follicle ruptures and the animal comes " in season " again.

In the normal healthy cow successive heats recur at fairly regular intervals of about twenty days throughout the year, though in winter the period of heat may be very short. In the mare the interval is about twenty-one days, but œstrus does not recur regularly during winter. In the sow the first heat occurs shortly after weaning, and in the non-pregnant animal recurs throughout the year at intervals of twenty-one or twenty-two days. In the ewe, by contrast with other species, œstrus is more or less confined to the autumn, the main controlling factor being length of day; thus ewes can be brought into œstrus during summer by subjecting them to nightly periods of darkness of twelve or

more hours. As would be expected, sheep kept in tropical regions show no breeding seasonality, and the length of the breeding season falls with increasing latitude. The peak of the breeding season, however, is usually somewhat before the shortest day. Again, the length of the breeding season varies from one breed to another. At the one extreme are the wild species, which ordinarily have only one or two heats per year; at the other is the Dorset Horn, which may have twelve or more. Most wild birds produce only a single clutch, or only two, during the year, but some, such as the wood pigeon, may have three or four. Domestic poultry may continue in full lay for many months; here, as in the case of sheep, day length has an important influence on ovulation.

Œstrus during pregnancy is abnormal, and it is ordinarily assumed that a female that has been mated, and has ceased to "come in season," is pregnant. But, on the one hand, it is not unknown for a pregnant female to show all the symptoms of œstrus, and to take the male. On the other hand, the *corpus luteum* sometimes persists in the non-pregnant animal much beyond the usual time—the case of so-called "false pregnancy."

Single ovulations are normal in the cow and mare, and it is doubtful whether twinning in these species is desirable under ordinary farm conditions, twins being, on average, less efficient than singles. In the ewe, double and treble ovulations are common, at least in certain breeds, if the level of nutrition and general well-being is high. Except under mountain conditions, a proportion of twins is desirable. In the sow, the number of eggs shed at each heat is generally of the order of twenty, but a considerable number of the embryos ordinarily degenerate at an early stage of development. Litters of twenty and over are, however, by no means very rare.

The average gestation period of the mare is about eleven months (340 days), in the cow nine months (280 days), in the ewe five months (150 days), and in the sow sixteen weeks (112 days). There is, however, a considerable range of variation.

Parturition, of course, normally coincides with the commencement of lactation, and the distention of the udder with colostrum is one of the signs that parturition is imminent. But animals on a high level of nutrition, and especially those that have been bred for high milk production, may begin to "run out" some time before giving birth. At the other extreme, females of

the specialized beef types, especially if they are in very low or overfat condition and have troublesome calvings, may have little or no milk.

After a female has given birth there is a longer or shorter interval before the recurrence of œstrus. In the mare this interval is short—commonly four to seven days. In the cow it is longer and less uniform, but commonly between one and two months. The sow rarely comes on heat while she is nursing a litter, but usually does so on the second or third day after the litter has been weaned.

The age at first œstrus depends to some extent on the breeding of the animal and the level of nutrition. Heifer calves may come on heat as early as six months of age and gilts at about four months. With spring-born ewe lambs some 70 or 80 per cent., on average, come on heat during the shortest-day period of their first year, the percentage being highest in those born early and well nourished throughout their lives. With late-born lambs reared under hill conditions the proportion is low, but it is still necessary to take precautions to prevent mating, which is very undesirable under mountain conditions.

Artificial Insemination.—Since a single ejaculation of semen normally contains many millions of spermatozoa, it is theoretically possible for a single male to beget vast numbers of progeny. In practice it is possible, by artificial insemination, to multiply the normal number from five to twenty-five times, and thus to exploit the value of a selected male. There is no great difficulty in collecting semen from the bull, ram, stallion, or boar. If the semen is diluted with a nutrient solution and is kept at an appropriate low temperature it retains its vitality, in the case of the bovine, for several days. Moreover, under deep-freeze conditions (−79° C.) vitality is maintained for a period of years. The advantages of deep-freezing are four, viz.: (1) The semen of a particular bull can be made available, in practice, at any time that it may be required (instead of only three or four days per week under cool storage); (2) a stock of semen can be retained after the death of the male animal which has produced it; (3) when there is a limited breeding season (*e.g.* in New Zealand dairy herds) collection of semen can proceed throughout the year, so that only a relatively small number of males need be kept; and (4) the insemination service is less liable to interruption by the occurrence of epidemic disease in the area served.

THE MECHANISM OF HEREDITY

The egg is a relatively large cell, containing a mass of protoplasm and yolk, together with a small nucleus—a clearly differentiated region with a characteristic structure. The sperm is a very minute motile cell with no yolk and very little cytoplasm (*i.e.* extra-nuclear protoplasm), but containing a nucleus that is similar in size and appearance to that of the egg. There is ample evidence that the bearers of the hereditary characters must be sought for in the nuclei of the germ cells. For one thing, the only portions of the egg and sperm that are comparable are their nuclei, and we know that, broadly speaking, the male parent has just as much influence on the characterization of the progeny as has the female. The nucleus of a cell that is in normal growth, or is carrying out its ordinary functions, contains a complex network of threads of a readily stainable substance called chromatin. When, however, cell division is about to occur, the chromatin threads condense, thicken, and assume the form of a number of generally rod-like bodies called *chromosomes*. These chromosomes are constant in number for all the cells of the individual and (with the significant exception mentioned below) for all the individuals of a race. Moreover, it can frequently be shown that each chromosome has a definite kind of individuality, for whenever particular members of a set can be recognized by size or shape, a group from one cell can be matched, member for member, with that from another. A further important fact is that the chromosomes occur in the body cells in pairs, and all the evidence points to the conclusion that of each pair one member is derived from the male, the other from the female parent. In the ordinary type of cell division (Fig. 27) each chromosome splits longitudinally into two like halves; the latter are drawn apart to opposite poles of the dividing cell, the nuclear wall breaks down and two nuclei are formed, each containing a complete set of the divided chromosomes.

In the division that gives rise to the reproductive bodies—the ova or the sperms—the process is essentially different from that just described. The condensation of the chromatin into chromosomes takes place much more slowly, and when the chromosomes finally appear they are found to be united in pairs. The long preparatory stage is believed to have to do with an exchange of like parts between the paternal and maternal members

of each chromosome pair. In any case the two members of each chromosome pair now separate, a further division follows immediately, and four nuclei are produced. The essential point is that the nucleus of each cell contains only half the number of chromosomes that is characteristic of the body cells of the species.

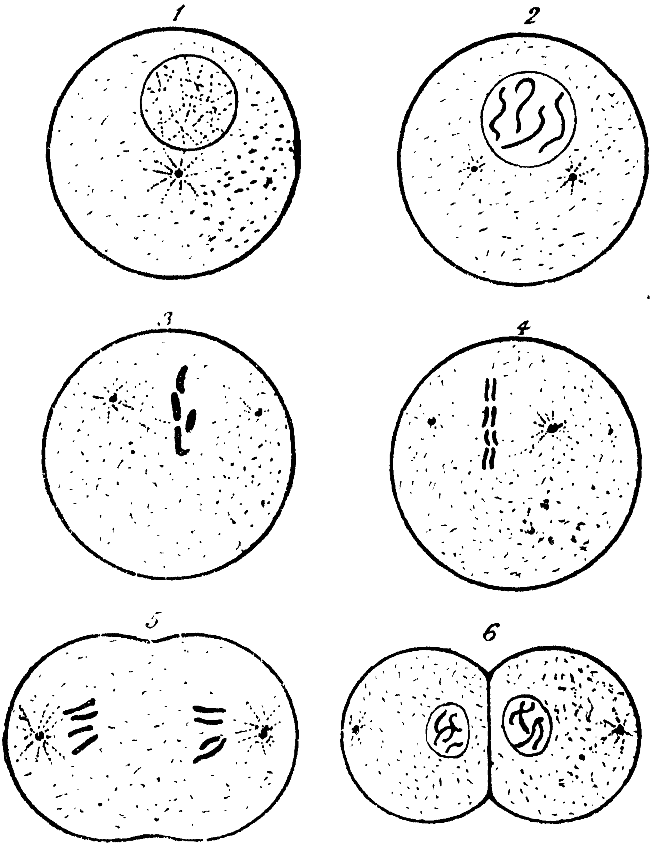


FIG. 27.—Ordinary Cell Division

Of the four cells, each, in the case of the male, becomes a functional sperm (see Fig. 28). In the case of the female, one becomes the functional egg while the others are cast off as the so-called polar bodies, which can be looked upon as abortive eggs. When fertilization occurs the sperm nucleus fuses with that of the egg and the original (or double) number of chromosomes is restored.

A further interesting point is that there is frequently a

characteristic difference between the set of chromosomes possessed by the male and by the female respectively. The one sex has a complete double set of chromosomes, the two members of each pair being like. The other sex has either one odd chromosome or else an unlike pair. Thus in the American Fruit Fly, *Drosophila melanogaster* (see Fig. 29), the female has four like pairs of chromosomes, and when reduction occurs, produces, so far as the chromosome-content is concerned, only one kind of egg. In the

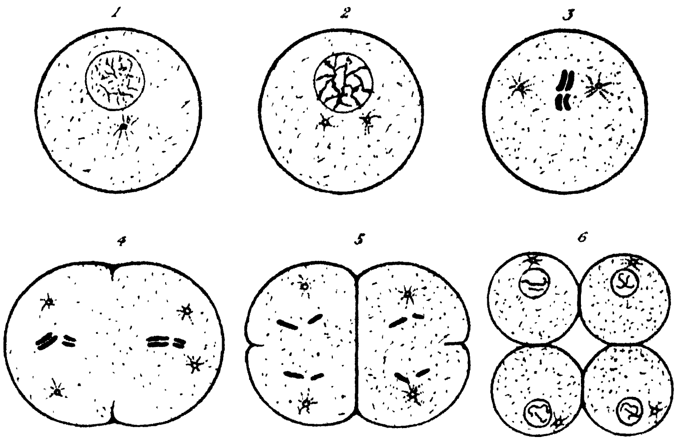


FIG. 28.—The Reducing Division—Formation of reproductive cells in the male

male, three pairs of chromosomes and one member of the remaining pair can be matched in the female set, but the second member of the last pair is recognizable from the others by its shape, which is sharply bent. The male thus produces two sorts of sperm-cells in equal numbers, half containing the straight chromosome (or X-chromosome as it has been called) and half the bent or Y-chromosome. It follows that eggs fertilized by the first sort will produce females, since they will possess the constitution symbolized by the formula XX; those fertilized by the second will develop into males, since they will have the constitution XY. The chromosomes thus provide a simple mechanism for the determination of sex. Apart from this, the facts just quoted are important in connection with what is called sex-linked inheritance, a peculiar phenomenon that arises from the circumstance that factors for other characters than sex are carried by the sex chromosomes (see p. 527).

The particular arrangement of the sex chromosomes just described is not universal. It is reversed, for example, in fowls, where the male is *homogametic* (producing but one sort of sperm

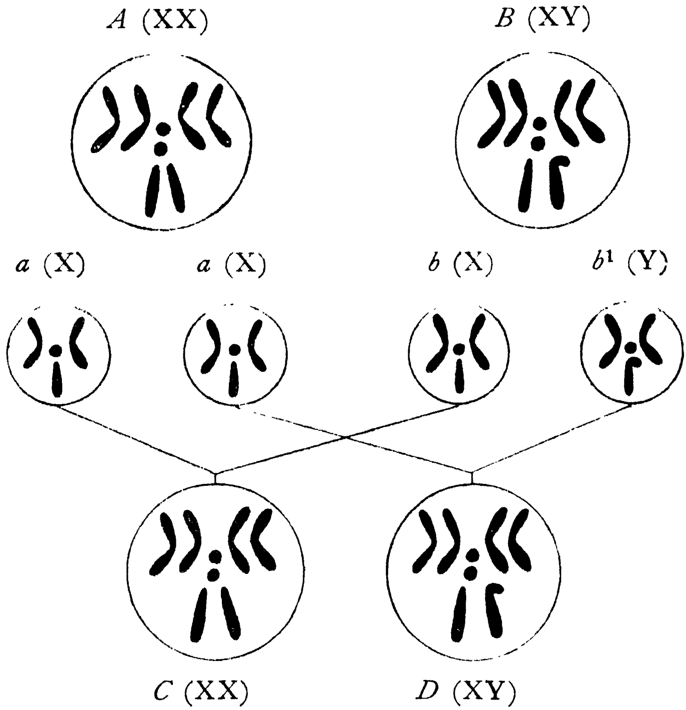


FIG. 29.—The Chromosomes in *Drosophila melanogaster*

A, female; *B*, male; *a*, *a*, ova; *b*, b^1, sperms; *C*, female zygote formed by union of sperm *b* with egg *a*; *D*, male zygote formed by union of egg *a* with sperm b^1

so far as chromosome-content is concerned), while the hen is *heterogametic*, giving rise to two sorts of ova, male-producing and female-producing respectively.

MENDEL'S FIRST LAW

Such being the mechanism and such the general theory of heredity, let us now turn to some of the observed facts of inheritance. In 1865 Gregor Mendel, as a result of some crossing experiments with garden peas, was led to make an important generalization regarding the manner in which parental characters

are distributed among the progeny. Varieties of peas show a considerable number of definite character differences—*e.g.* some varieties are tall, others dwarf, some have round seeds, others wrinkled, some green seeds, others yellow, and so on. Moreover, the plants are self-fertilizing, and varieties, as a rule, breed true to their own particular characters. Mendel's method was to cross two types showing some definite character difference; if the two varieties showed more than one such difference he considered each difference without reference to the others. He reared the hybrid plants and allowed them to become self-fertilized; in the next or second hybrid generation he classified the individual plants with reference to the original parental characters, and counted the members of each group. In one experiment, for example, Mendel crossed an ordinary tall variety with one of the well-known dwarf sorts, both varieties being known to breed true to their respective types. The first-cross plants were tall like the tall parent—indeed, they somewhat exceeded the latter in height. These hybrid talls did not, however, breed true. On the contrary, when allowed to become self-fertilized, they produced tall and dwarf progeny in the proportion (roughly) of three of the former to one of the latter. Mendel's actual figures were 787 tall and 277 dwarf, or 73 and 27 per cent. respectively. When these second-cross plants were tested individually (by making separate sowings of the seeds of each), it was found that all the dwarfs bred true. Of the tall second-cross plants a proportion, about one-third, were found to produce nothing but tall progeny, while the remainder gave talls and dwarfs in the same ratio as did the first cross. These results may be summarized in the following scheme:—

Pure tall — Dwarf

Hybrid tall

1 Pure tall : 2 Hybrid tall : 1 Dwarf

Tall — 1 Pure tall : 2 Hybrid tall : 1 Dwarf — Dwarf

The fact that the first cross resembled the tall parent and showed no sign of the dwarf character was expressed by Mendel by saying that "tallness" was *dominant*, and "dwarfness"

recessive. Dominance, however, is by no means universal; sometimes a hybrid shows a condition somewhat intermediate between those of its parents. For instance, if a red-flowered variety of *Mirabilis jalapa* (Marvel of Peru) is crossed with a white, the hybrid bears pink flowers. If the hybrid is selfed and a second hybrid generation is reared, the ratio obtained is 25 per cent. red, 50 per cent. pink, and 25 per cent. white. The reds and whites so obtained breed true, while the pinks of the second

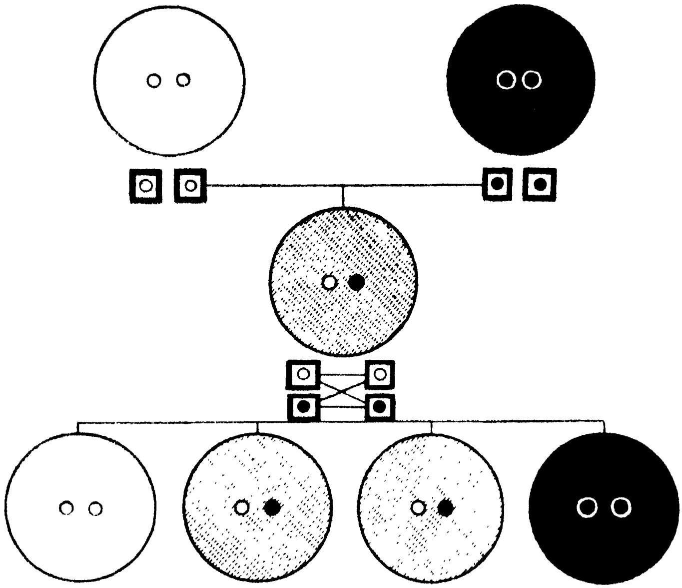


FIG. 30.—Cross between Red and White Varieties of *Mirabilis jalapa*

The large circles represent the parent, first hybrid, and second hybrid generations, and the small circles the genes. The squares represent the reproductive cells

generation give the three types in the same ratio as did their parents. Thus whether or not there is dominance in a particular case, the general result is the same. When hybrids are self-fertilized or interbred they produce, with regard to any particular character, three types of progeny; the original parental types are each reproduced in one-fourth of the second hybrid generation, while the remaining half are hybrids like the first cross.

Mendel not only discovered this general rule of inheritance but he proposed an explanation of the facts. His hypothesis still stands. Subsequent research has brought out much evidence in

its support, and has served to develop rather than to modify the original theory. Mendel knew nothing of chromosomes, but the facts regarding their behaviour fit in remarkably well with the phenomena that he observed, so that to-day we may best state Mendel's hypothesis in terms of the chromosomes. We assume, then, that a "factor" or "gene" controlling, say, the flower colour of the *Mirabilis*, is borne in one of the chromosomes of the species. A red-flowered plant will have a red-producing gene in both members of the chromosome pair concerned, and since each egg or pollen cell that it produces will receive one member of the pair, only one type of reproductive cell will be produced. The white-flowered plant will contain "white" genes in the corresponding region of its corresponding chromosome pair, and all its reproductive cells will carry the white factor. When the two varieties are crossed it is obvious that the hybrid will have a pair of chromosomes that are unlike with regard to the gene for flower colour, one having the red factor and the other the white. What visible result will be produced by such a combination is not capable of prediction, but in the present case we saw that the hybrid had pink flowers. Now the essential point of the theory is that the two genes do not intermingle but remain throughout the life of the plant as separate and distinct entities. When the reproductive cells are formed, and the two members of the chromosome pair separate, half the ova and pollen grains will receive a chromosome containing the "red" gene, while the other half will get one containing the "white." The pink plant produces, then, reproductive cells that carry not a factor for the pink character but that for either the original red or the original white, and the two classes occur in equal numbers. When the hybrid pink plants are selfed, fertilization of either type of egg by either type of pollen grain occurs as a matter of "pure chance," so that the following four combinations are equally probable, viz.: "white" pollen grain with "white" egg; "white" pollen grain with "red" egg; "red" pollen grain with "white" egg; "red" pollen grain with "red" egg. The first combination will produce a white-flowered plant, the last a red, and the second and third pinks that are not distinguishable, since it is immaterial whether the red is introduced from the male or the female side. Thus is produced, it is suggested, the ratio of 1 red : 2 pink : 1 white.

The actual numbers obtained in Mendelian experiments are subject to chance variations, and do not, except by chance, give

exactly the "expected" ratio. The numbers can be predicted only in so far that we can state the most probable result, just as we can in the case of, say, a series of tossings of a coin. Thus if we make a hundred throws, the most probable single result is fifty heads and fifty tails, but the probability of obtaining fifty-one or forty-nine heads is only very slightly less, and so on through the whole series of possibilities. When, however, large numbers are dealt with, the ratio should approach very closely to theoretical expectation, and this has been the case in Mendelian experiments. For instance, one of Mendel's original experiments, dealing with cotyledon colour in peas, has been fourteen times repeated by different experimenters, and a total of 203,500 second hybrid individuals have been bred. Yellow colour is completely dominant to green, so that the expectation was 3 yellow, 1 green; or altogether 152,625 yellow and 50,875 green. The totals actually obtained were 152,824 yellow and 50,676 green—a ratio of 75·1 per cent. to 24·9 per cent.

If the hypothesis that has been outlined above is adequate, it ought to enable us to predict the results of a mating between any two of the three possible types. For example, if we cross the pink (heterozygous [1]) *Mirabilis* back to the parent red form we should expect the following two combinations in equal numbers: "white" pollen and "red" egg cell, giving pink; "red" pollen and "red" egg cell, giving red. Similarly a cross of pink and white should give us pink and white progeny in equal numbers. Results of this sort have been regularly obtained.

Mendel's first law may, therefore, be stated thus: When a dissimilar pair of factors are brought together in crossing they separate again when the hybrid produces its reproductive cells. The separation is clean and complete. The hybrid condition cannot be represented in the sperm or in the unfertilized egg—it can only be produced in the fertilized egg, and then by the union of an egg and a sperm that are dissimilar with regard to the factor in question.

MENDEL'S SECOND LAW

Mendel's second generalization was to the effect that when two or more character pairs are considered simultaneously each pair behaves without reference to the others. Since Mendel's

[1] Heterozygous, since it received from its parents dissimilar factors for the character now being discussed, a "red" factor from the one and a "white" from the other.

time, indeed, a very important group of exceptions to this law has been discovered, and the evidence leads to the conclusion that these exceptions arise in cases where two pairs of genes are contained in one and the same pair of chromosomes. With this reservation, Mendel's second law is true. Take, for example, the results obtained in crossing a tall purple-flowered variety of pea with a dwarf white-flowered sort. The tall condition is dominant to the dwarf and coloured is dominant to white. The first cross is, therefore, tall purple. If these plants are selfed and the succeeding generation reared we get, of course, the ratios of 3 tall : 1 dwarf and 3 purple : 1 white. But the two dominants do not necessarily go together. On the contrary, the tall group will consist of purples and whites in the ratio of 3 : 1; the whites will consist of 75 per cent. talls, 25 per cent. dwarfs, and so on. Hence the combined ratio is obtained by algebraic multiplication of $(3\ T + 1\ D) \times (3\ P + 1\ W)$, giving 9 tall purple : 3 tall white : 3 dwarf purple : 1 dwarf white. It is obvious that very complex ratios will be produced when three or more character pairs are considered simultaneously. It was this complexity, apparent rather than real, that baffled all Mendel's predecessors, and it was Mendel's plan of dealing with one thing at a time that brought out simplicity and order from seeming chaos.

One or two somewhat odd cases must be described in which, though inheritance is strictly Mendelian, the results are complicated by reason of the effects produced by particular factors. One of the earliest discovered cases had to do with the inheritance of yellow coat-colour in mice. The first peculiarity of the case is that yellow mice never breed true; in matings of yellows with yellows the young are about two-thirds yellow and one-third of other colours. Yellows are never produced from matings of two non-yellows. If yellow is mated with non-yellow the young consist of equal numbers of yellows and non-yellows. These facts indicate that yellow is dominant, but that all yellow mice are heterozygous for the yellow condition. If two such are mated, the expectation would be 1 pure yellow : 2 hybrid yellow : 1 non-yellow, and the only explanation of the facts is that the pure or homozygous yellow is incapable of life. This has found confirmation in the fact that in yellow × yellow matings a proportion of the embryos die in the early stages of development. Why the homozygous yellow should be incapable of life beyond this early stage is not known, but it is interesting to note that even the hybrid yellows

are not quite normal, being distinctly less hardy than non-yellows, and liable to become excessively fat. A further interesting fact is that many analogous *lethal factors*, leading to structural abnormalities or functional derangement of such an order as to render the individual incapable of living, have been discovered in several species, including cattle and sheep.

A very striking result of hybridization was obtained in the course of some of the earlier experiments with sweet-peas. Two white varieties gave a purple first cross. This occurrence can properly be classed as a reversion, since the wild parent of our cultivated forms is purple-flowered. These crosses, when left to become self-fertilized, gave progeny in the ratio of 9 purple : 7 white. In other crosses between two whites, other colours than purple were obtained in the first cross, and sometimes the second hybrid generation contained a mixture of coloured types, the proportion of coloured to white remaining, however, that of 9 : 7. Moreover the whites, when self-fertilized, always bred true; some of the coloured types produced only coloured progeny, while others gave one-fourth and still others seven-sixteenths of whites. The explanation of this case is that colour is produced only in the presence, simultaneously, of two dominant factors. One of the white varieties contains the first of these factors but lacks the second; the other has the second but lacks the first. The first hybrid thus contains both dominants and is coloured. In the second hybrid generation we get as usual a 9 : 3 : 3 : 1 ratio, the last three classes lacking respectively one or other or both dominants, and hence being white. Many implications of this theory have been tested and the expected results obtained. The occurrence of different colours in the second hybrid generation is explained by the fact that white sweet-peas may carry various factors capable of modifying colour although, in the absence of the colour factors themselves, these can have no visible effects.

A long series of similar cases might be described; none of them, however, constitutes an exception to Mendel's two laws. The complications arise out of the visible effects of the factors, and the factors themselves behave in the normal way.

LINKAGE

It was not until some ten years had been spent in active Mendelian investigation that any new principle was discovered.

The first cases that failed to conform to Mendel's second generalization were found in sweet-peas. In one of these cases a variety with purple flowers and an ordinary erect standard petal was crossed with another having red flowers and a hooded standard. It was previously known that purple behaved as a simple dominant to red, and that the erect standard was a simple dominant to the hooded. The first hybrids were purple erect, according to expectation. Had the case been normal the second hybrid generation should have consisted of the four possible combinations in the proportions 9 purple erect : 3 purple hooded : 3 red erect : 1 red hooded. The actual numbers obtained were 2036 purple erect : 12 purple hooded : 10 red erect : 654 red hooded. The numbers show that the two dominant factors on the one hand and the two recessives on the other have somehow "stuck together" in a great majority of cases. The numbers, in fact, strongly suggest the simple ratio of 3 : 1—three double dominants to one double recessive. But the other two classes, each containing one dominant only, do occur, though relatively very rarely.

When the cross was made between two parent plants with the same characters in the opposite combinations the result was quite different. Purple hooded crossed with red erect again gave a purple erect first cross. In this case, however, the second hybrid generation consisted of 2969 purple erect : 1369 purple hooded : 1441 red erect. The fourth possible class, *i.e.* the double-recessive red hooded, did not occur at all. Here, again, the results suggest a simple monohybrid ratio—viz. one-fourth like each of the original parents and one-half like the first cross. It is obvious from the second experiment that the case is not one of attraction between any two characters as such. The point is, however, that the characters are combined in the original parents, these combinations tend to persist and to reappear in the second hybrid generation. The old combinations are broken and new combinations made only in a small minority of cases.

This phenomenon of *linkage*, as it is called, arises whenever two pairs of genes are carried in one and the same pair of chromosomes. For a full explanation the reader is referred to any standard work on genetics.

In the examples quoted above there are *pairs* of Mendelian factors—*e.g.* tall and dwarf in peas, red and white in *Mirabilis*. But many cases are known of *multiple allelomorphs*. Bay, black,

and chestnut colour in horses constitute such a series—*i.e.* a bay horse may carry the factor for black or chestnut (but not both) while a black may carry chestnut. The dominant grey factor is separately inherited; only in its absence can a horse be of any other colour.

QUANTITATIVE INHERITANCE

The vast majority of economic characters of farm animals—size, milk yield, egg production, quality of wool, etc.—in so far as they are influenced by heredity, depend on a large number of genes, whose individual effects cannot be isolated. Such are known as polygenic characters. Moreover, as is well known, such characters are influenced not only by heredity but also by environmental conditions. Thus, a Friesian cow (apart from the possibility that both her parents carried the recessive red factor) will be black and white whatever the conditions under which she is reared. But the expression of her genetic milk-producing capacity will vary with age, disease, level of nutrition, the degree of skill exercised in management and milking, and many other circumstances. Under extremely unfavourable conditions her actual milk yield will bear very little relation to her genetic make-up.

Hence a useful distinction can be drawn between the *genotype* and the *phenotype*. The genotype is the result of the random union of gametes produced by Mendelian segregation within the restrictions caused by linkage. The phenotype is determined partly by genetic and partly by environmental forces, and by the interaction between the two.

The relative influences of heredity and environment vary as between one character and another. For example, in the dairy cow the butter-fat content of the milk is much more a matter of heredity, and much less a matter of environment, than milk yield. The proportion of phenotypic variation of a particular quality that is due to heredity is termed its *heritability* and is commonly expressed either as a decimal fraction or as a percentage of the total variation. Thus the heritability of the butter-fat content of milk, within a given herd, is commonly about 0·4 (40 per cent.) while that of milk yield is much less—20 or 25 per cent. Thus it is easier to breed for butter-fat than for milk yield.

SEX-LINKED INHERITANCE

A complication is introduced in the transmission of certain characters owing to the fact that their factors are carried by the sex chromosomes. In poultry, for example, the male has a like pair of sex chromosomes while the hen has only one functional or gene-bearing sex chromosome. The result of this condition of affairs is illustrated by the behaviour of the barred pattern of the Barred Rock, which is dominant to black and sex-linked. If a pure-breeding barred cock be mated to black hens, the progeny are all barred. In the second generation the males are all barred and the females half and half as to colour. When the cross is made in the opposite direction—black cock with barred hens—the male chicks are barred and the females black (criss-cross inheritance). In the second hybrid generation we get the four classes—black males, barred males, black females, and barred females in equal numbers. The mechanism is illustrated in Figs. 31 and 32.

The explanation of all sex-linked cases is essentially the same. One of the sexes—the female in the case of the domesticated fowl—has only one functional or gene-bearing sex chromosome. This it obtains in every case from its parent of the opposite sex. The other sex has a pair of gene-bearing chromosomes, one derived from either parent, and therefore the normal complement—a double set—of the sex-linked genes. Its visible characters, in the event of the genes being different, are determined by dominance.

Sex-linkage has an important application in poultry breeding (see Chapter VIII), since with certain crosses the sexes of the chicks can be distinguished immediately on hatching.

We may now summarize our general conception of heredity. The hereditary characters of an animal are determined by a double set of factors or genes—one set derived from either parent. The sole exceptions to this rule are the sex-linked characters which, in one or other of the sexes, are represented by single genes only. Ordinarily each visible character is the resultant effect produced by a pair of genes, whether the two members of the pair be like or unlike; sometimes the effect of one gene is so strong as completely to mask that of its fellow (dominance). When the individual produces its reproductive cells and the chromosomes are reduced to half their original number each egg or sperm cell receives either the one or the other member of each pair of genes—that is, it receives a single set. The mechanism controlling the

distribution of the genes between the reproductive cells is such that certain pairs assort quite independently of others. This happens when they are situated in different chromosomes. There is, however, a tendency, definite and measurable in particular

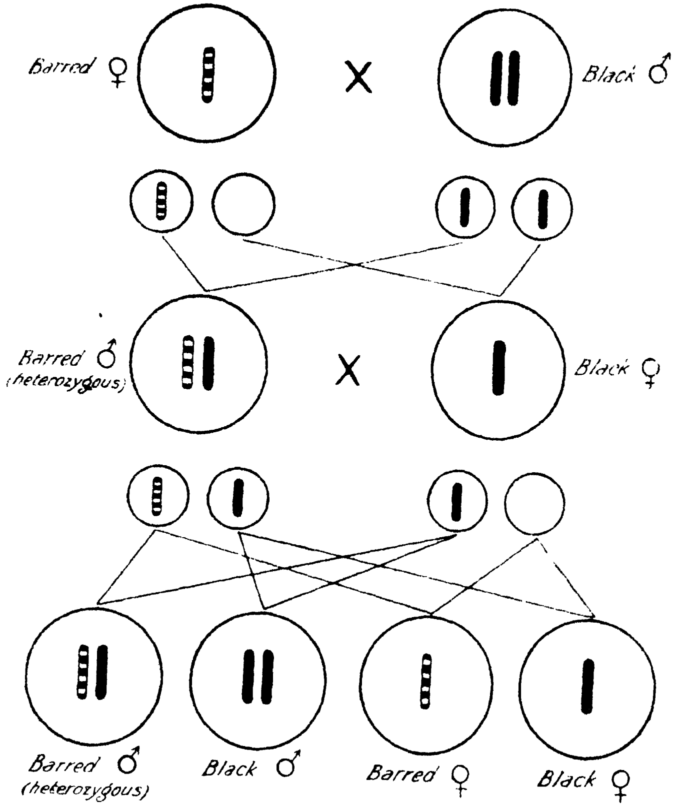


FIG. 31.—Inheritance of Barred Pattern in Fowls

cases, for certain genes to stick together in pre-existing combinations (linkage). This, it is believed, is due to their occurrence in one and the same chromosome. Linkage, however, is normally only partial, so that the chromosome cannot be regarded as a permanent or immutable assemblage of genes.

The heritage of a breed or race consists of the sum total of unit characters represented in the chromosomes of its individual members. The great bulk of observed variation between individuals of the same race (in so far as it is not due to conditions of nurture)

is due to the process of biparental inheritance. This involves a combination, in each individual, of two sets of genes, one derived from each parent, and a reshuffling of these before they are handed on, in the germ-cells, to the next generation. A race will breed

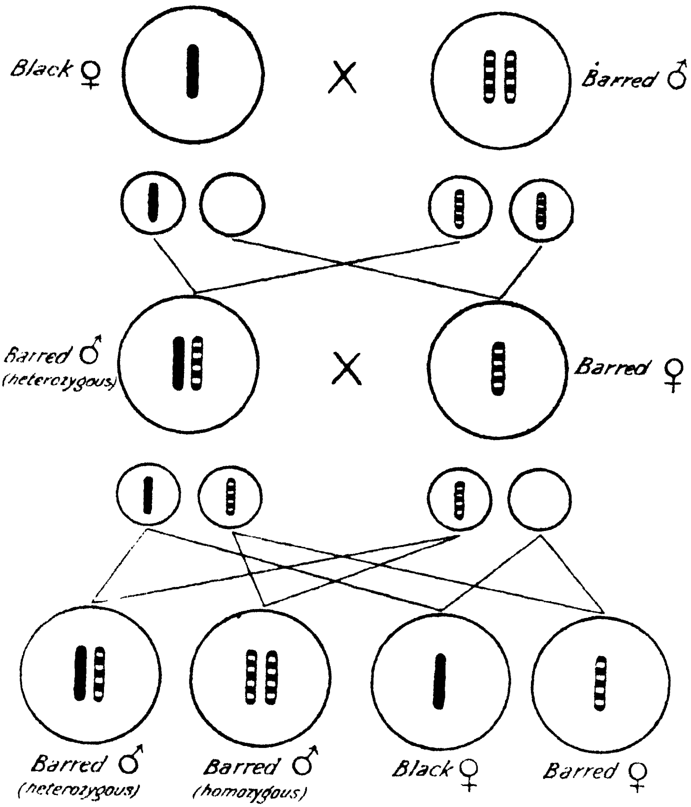


FIG. 32.—Inheritance of Barred Pattern in Fowls

true to all its characters only when each and every pair of genes consists of two identical members, *i.e.* when the maternal set of genes is exactly matched by the paternal.

PURE LINES

It is worth while to look into this last hypothesis and see whether it will stand the test of experiment. The effect of biparental reproduction is to maintain a large number of characters in the

heterozygous condition, and thus to produce a large amount of variation. In fact, the whole significance of sexual reproduction seems to be that it makes possible a great series of character combinations and thus gives the race as a whole the power to adapt itself to changing conditions. Among higher animals, therefore, we cannot expect to find true-breeding strains unless we employ artificial means to produce them. Many plants, however, have abandoned biparental reproduction, resorting either to vegetative methods or else to self-fertilization. In either case we get rid of the complexities produced by the reshuffling of genes in each successive generation, and therefore we should expect to find fixed, true-breeding strains. Such variations as occur within the strain must be due to causes other than heredity—*i.e.* to environmental causes—and should not be transmitted. This theorem has been put to the test in many experiments, and the results, in every case, have been in agreement with it. For example, if we take a single barley plant, descended, as normally it would be, from self-fertilized ancestors, it will produce a group of progeny having strictly the same hereditary characters as itself. Such a group of progeny, constituting what is called a *pure line*, is fixed, because all its members have the same set of characters in the homozygous condition. Selection within a pure line accomplishes nothing, because selection can produce results only where hereditary differences exist. Cross-fertilization between plants of the same pure line is likewise without effect, for it amounts to nothing more than a combination of like with like. We are therefore justified in concluding that, as a rule, the individual genes remain constant from one generation to the next, and that the bulk of observed variation among the members of a breed or race is due to reassortment of unit characters and not to any change in the unit characters themselves. This is important from the practical point of view, for it implies that there is a definite limit to the possibilities of selection. When we have obtained a certain combination of characters, all in the homozygous condition, we get no more variations of hereditary value and hence further selection is a ploughing of the sands.

Such is true in the main; the units that compose the hereditary material are of definite constitution, and normally they remain constant. But occasionally, for reasons that are not understood, the genes do change. And when change occurs it is of the nature of a definite step; the new character is fully as constant as the old

and behaves as a Mendelian alternative to it. Such sudden and definite changes in the hereditary material are known as *mutations*; they have been seen to occur in most species of plants and animals that have been kept under continuous and close observation; they are not necessarily connected with sexual reproduction—vegetative sports being relatively common. Sometimes they are obvious and startling, more often they are to be detected only upon close scrutiny, and it is certain that many have passed unobserved or have not been distinguished from the ordinary sort of variation due to recombination of factors. Mutations can be produced in plants by treatment with certain chemical substances and by certain ray treatments, but their direction cannot be controlled and nothing of economic value has so far been produced by artificial means. All that the breeder can do is to watch for their occurrence and to perpetuate such as happen to prove of use.

Mutations, as has been said, occur only rarely. In small laboratory animals, which can be bred in large numbers, it has been possible to estimate their frequency. In the fruit fly (*Drosophila*) the total mutation rate is about 0·7 per cent., *i.e.* seven out of every thousand sperms or eggs carry a mutation in one or other of their genes. The total number of genes in *Drosophila* is probably of the order of five or six thousand, so that, on average, the chance of a mutation in a particular gene is slightly more than one in a million. Moreover, of the many mutations that have been observed in farm animals, very few have been of economic value. Yet in the mass, the mutations that have resulted —*e.g.* in the evolution of the superfine merino fleece from the hairy coat of the original wild sheep—have been of immense importance.

LIVE-STOCK IMPROVEMENT

The business of the constructive breeder who sets out to improve his herd rather than merely to multiply it is to build up a certain combination of valuable hereditary characters—that is, to produce a good type of animal that will "breed true" to its good qualities. Obviously the first essential is a definite object, a clearly conceived ideal type. Moreover, this ideal should be no mere arbitrary standard of "points" but should be laid down with regard mainly to economic considerations—that is to say, our ideal animal should be that which will convert its food

into meat or wool, milk, or work, as the case may be, with a maximum of efficiency.

In certain cases it is easy to devise a simple and direct test of economic worth. It is so, for example, in the case of milk or of wool production, because it is possible in both instances to determine both the yield and quality of the product and to take such determinations as a basis for selection. The usefulness of a work animal is more difficult to assess, because no final judgment can be reached until the end of its working life. With meat-producing animals, again, no complete or definite information can be obtained on such important points as the quality of the meat, or the proportion of carcass to offal, until the animal has been slaughtered. In general, however, any direct test is preferable to a mere inference based on the animal's outward appearance, and there is an increasing tendency to apply such direct tests wherever possible. With pigs, for ex . ıple, prolificness can be recorded and the milking capacity of a sow can, for practical purposes, be sufficiently measured by determining the live-weight increments of her piglings during the period when they are solely dependent on their dam's milk. The efficiency of the animal in converting food into meat can be expressed as a ratio between its weight increment and its food consumption, and even on such a matter as the quality of the meat of a breeding animal, inferences can be drawn with some degree of certainty if a few of its litter brethren or its progeny be fattened and slaughtered.

It is important to note that improvement implies the closer adaptation of the animal to the environment in which it is expected to live, and that a breed or strain that has been improved in relation to one type of environment may have been made less well adapted to another. For example, the type of sheep that has been evolved for lowland conditions, which grows and fattens rapidly on abundant and nutritious food, lacks the agility to find its food on a mountain pasture, and its requirements for minerals to make bone, and for protein to make flesh, are so high that it cannot collect the necessary supplies of these nutrients from the poor herbage and hence its growth is stunted. Again, when we speak of a highly productive dairy cow we really have in mind a type of animal that is capable of converting a large supply of nutrients into milk. Such an animal may be quite unsuited to a poor upland farm, because her milk production will tend to outrun her intake of nutrients and she will lose condition and powers of

resisting disease. As a third example, the bacon type of pig is intended to produce a lean type of carcase with the least possible consumption of food. But if food is restricted in the early stages the development of lean tissue will be inhibited, and heavy feeding at a later stage will result in a large development of fat, so that the final product will not be what is desired. The expression of the animal's hereditary merits thus depends on the provision of appropriate living conditions.

When Bakewell,[1] the great pioneer breeder, started the improvement of British live stock about the middle of the eighteenth century, the farm animals of the country were of very mixed type and of a low average standard of merit. Certain local types were distinguished by peculiarities of size, prevailing colour, etc., but there were no breeds in the modern sense. In all these local types there seems to have been a great amount of variability with respect to useful qualities. Probably there were many individuals with one or other good quality, and occasional specimens showed chance combinations of several valuable qualities; but ancestry was mixed and transmission apparently very irregular. The initial step in the improvement of each breed in turn, by one improver after another, has been to collect a herd or flock of the best individuals of the local type, and so to get possession of all the qualities that it was deemed advisable to perpetuate in the improved breed. If it happened that several of these characters could be obtained already combined in one individual, then the work of building up the desired combination would be rendered less intricate and tedious. But the main point is that the breeder could not expect, except as a rare piece of good fortune, to get any actual change in the individual unit characters with which he started—a favourable mutation. And hence the real essential in the foundation of a herd was to get together as many good characters as possible, even if this involved the introduction of some bad. For bad characters could be "bred out," whereas there is no known method of producing good characters *de novo*. Apparently Bakewell, when he laid the foundations of his Leicester flock, succeeded in gathering together all the characters that were essential to the making of a good long-wooled sheep, mixed up as they were with a greater

[1] Robert Bakewell of Dishley in Leicestershire, *b.* 1726, *d.* 1795, originator of the improved Leicester sheep and the improved Longhorn cattle, and breeder of cart-horses and pigs.

number of undesirable qualities. On the other hand, his work with the Longhorn cattle of the Midlands was destined to comparative failure, apparently because elsewhere, in the valley of the Tees particularly, there was a supply of better raw material—a local type of cattle among which there lay scattered a set of more valuable unit characters.

Having started on a basis sufficiently wide to ensure the inclusion of all the characters desired, the breeder proceeds, by successive matings and selection of the progeny, to weed out undesirable characters, and to combine the good qualities first in an individual or two and finally in a true-breeding strain. This process, it is true, has never yet been carried to the point of complete or final success, yet so much progress has been made that it is important to survey the methods by which it has been achieved.

MASS AND PEDIGREE SELECTION

The simplest form of selection is what is termed mass or phenotypic selection—the choice of breeding-stock on the simple basis of individual merit. The application of this process has given very different results according to the kind of characters to which it has been applied. Obviously the degree of success attained will depend on the accuracy with which the genetic make-up is reflected in the visible or measurable characters. If a certain visible character represents a certain definite and pure (homozygous) condition in the germ cells then we are on perfectly safe ground. Thus if we wished to obtain a race of single-combed fowls from a mixed population, a system of mass selection would give immediate and completely successful results, because we know that a single-combed fowl can have in its germ cells nothing but the "single" factor in the homozygous condition. For various reasons, however, the visible characters of the animal may be unsatisfactory, or even quite misleading, as a guide to the qualities that it is capable of transmitting. Characters like egg-production in fowls or milk-production in cattle are determined in part only by heredity, being influenced to a very marked extent by the conditions of "nurture" in the widest sense. Even when, in the case of a milch cow, we calculate the allowances for the grosser effects of age, time of calving, feeding, etc., we are left with a multitude of varying environ-

mental conditions whose total influence it is impossible to assess. We must therefore proceed on the assumption that milk-yield is in large measure a matter of accident or "pure chance," and is only in part determined by heredity.

Even when a certain desirable quality is known to be solely a matter of heredity, mass selection often fails to give the desired results. This happens if the character in question is dominant to a corresponding undesirable condition. For example, in cattle the red colour is recessive to most others, and is completely dominant to none [1]; hence reds breed true, and mass selection is immediately successful in establishing a true-breeding red strain. With Angus cattle, on the other hand, the recognized black colour is completely dominant to red, *i.e.* there is no visible difference between the homozygous black, which breeds true, and the black × red heterozygote which throws reds. The consequence is that red calves occasionally turn up in most herds even though their ancestors may have been black for generations.

There is still another set of circumstances in which simple selection fails to accomplish anything. This happens when a particular quality is due to a hybrid condition of the germ-plasm. Thus the pink colour in *Mirabilis*, the blue of the Andalusian fowl, and also the roan and the blue-grey colours in cattle, are each due to a heterozygous condition, and it seems that one might breed from any of these types for countless generations and still be no nearer to a true-breeding strain.

Pedigree, when rationally used, forms a valuable aid to the breeder in his work of selection. Pedigree must never be regarded as an end in itself; individual merit must always be considered first—but the two taken in conjunction are undoubtedly a far better guide than either considered alone. The essential questions that a breeder should ask himself in attempting to evaluate a particular pedigree are: (1) What was the average merit of the animal's immediate ancestors? (2) What evidence is there that their good qualities were regularly transmitted from generation to generation? If we have a good individual, the progeny of good and true-breeding parents, it is probable that it will transmit its good qualities. The commonest error in the interpretation of pedigrees is that of attaching undue importance to far-back ancestors, and in particular to descent in the direct female line from particular

[1] This statement does not apply to white markings. Some types of white pattern are recessive to solid colours.

"foundation females." It is quite certain that the average influence of any single animal in even the third or fourth ancestral generation is very slight indeed, and it is doubtful whether in practice there is much to be gained by looking back beyond three generations.

GENOTYPIC SELECTION

The third and by much the most effective method is what biologists call *genotypic selection*—that is to say, selection on the basis of breeding ability, as determined by actual tests. The special value of this system arises from the fact that it enables the breeder to form a far truer estimate of the hereditary characters than he can do either on the basis of individual merit alone or on the dual basis of individuality and pedigree. We may illustrate the method by reverting to the previous illustration of the red Aberdeen-Angus. If it were a matter of prime importance to get rid of the red colour once and for all, the essential thing would be to breed from parents that were homozygous for black colour. If both parents were homozygous blacks, then the calves would all be homozygous blacks. But even if we made sure of one parent only, we should, for the time being, prevent the appearance of reds, and by continuous breeding from homozygous black on one side we should very quickly reduce the number of the black × red hybrids in the herd. In practice this is all that could be done, because it is impracticable to carry out breeding tests with females of the slower-breeding species; half the cow's breeding life might be over before one could get presumptive evidence of her germinal constitution. Genotypic selection would therefore be confined to the bull, and the procedure would be to mate him with, say, ten or a dozen red or white or red-roan cows. If he were a homozygous black, all his calves would be black or blue-grey. If he left any red or red-roan calves one could definitely conclude that he was a black × red heterozygote, and therefore he would be discarded.

A similar procedure may be adopted with regard to any other character or group of characters. If the trial matings be made with carefully chosen females, and if the progeny be sufficiently numerous, a very complete picture can be obtained of the germinal constitution of the sire. Thus the best test of the capabilities of a dairy bull is the average production of a number of his daughters compared with the average production of their dams. With

meat-producing animals, too, the most satisfactory basis on which to judge a sire would be the economy of production and the quality of the meat produced by a number of his progeny. Such experimental tests are actually made with pigs by official testing stations in Canada, Denmark, and other countries; groups of four progeny of each sire are reared, fed, and finally converted into bacon under carefully controlled conditions, and the results are used in the final selection of stud animals from among the sires. In the United States, progeny testing by similar methods is being applied to bulls of the beef breeds. Such results are very valuable, for they constitute a test of the true commercial value of the animal under ordinary farm conditions.

FIXING TYPE

When there has been obtained an animal with something approaching the desired set of hereditary characters, the problem arises of maintaining or fixing this combination in a herd or flock or strain. It is true that no breeder has yet succeeded in producing a perfect animal, or even one possessing a full complement of all the best characters of its breed; yet success in the breeding of really fine individuals is comparatively common. It is far more difficult to build up a herd in which the good qualities are transmitted in any complete or regular fashion. Take milk-production, for example. Individual yields of 2000 and 3000 gals., and even more, have been obtained. The best herds, on the other hand, produce averages of between 800 and 1200, and this under a system of continuous culling—that is to say, the average is not that of the females bred but the average after a considerable proportion of the poorest producers has been discarded. In many countries the average production is 400 gals. or less. Admitting that milk-production is influenced by many circumstances other than heredity, one cannot avoid the conclusion that it is extremely difficult to get a fixed and true-breeding strain of heavy producers. It is obvious, too, that this end is of far greater importance than that of securing a few high individual records.

INBREEDING

It has been known since the time of Bakewell that inbreeding—the mating together of closely related animals—is a valuable aid in the fixing of type, *i.e.* in the production of strains in which the

same characteristics are regularly reproduced. The discovery by Bakewell of the value of inbreeding seems to have been due to the accident of circumstances. He had new and original notions as to what constituted merit in a sheep or a steer, and after he had formed his flock and herd, and had gone some way with their improvement, he naturally found it increasingly difficult to obtain, from outside, sires that he considered good enough to introduce. He therefore turned to home-bred sires, and gradually, as his blood lines became intermingled, he resorted to more and more intensive inbreeding. On the whole his results were exceedingly good.

This effect of inbreeding, the fixing of type, is readily explicable on the Mendelian hypothesis. If we take a group of plants that are heterozygous for a particular character—say a hundred pink-flowered *Mirabilis*—and cause them to become self-fertilized, 50 per cent. of the progeny will be heterozygous, *i.e.* pink, while the other half will show one or other of the homozygous conditions, white or red. If this generation is selfed again the whites and reds breed true, while the pinks produce 50 per cent. of the hybrid (pink) and 50 per cent. of the homozygous (white and red) forms. Thus if the various forms are allowed to multiply in the same ratio, the proportion of heterozygous or non-pure-breeding types decreases from generation to generation in the series $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, and so on. After ten generations of self-fertilization the pure types would constitute 99·9 per cent. of the population. Similarly, if we start with a multiple hybrid—*i.e.* with a plant having a large number of characters in the heterozygous condition —and if we neglect the complication of linkage the *average* number of heterozygous characters will be halved each time that self-fertilization occurs. If, for example, we cross two varieties of wheat that differ in sixteen Mendelian characters, and allow the progeny to self-fertilize for a dozen generations, it may be calculated that over 99 per cent. of the progeny will have automatically reached the homozygous or true-breeding condition.[1] This is in accordance with the discovery, made independently, that in species that are regularly self-fertilized the vast majority of individuals do actually breed true.

Self-fertilization is, of course, the most intense form of inbreeding that it is possible to conceive, but other forms differ

[1] In fact the occurrence of linkage slows down the rate of progress towards homozygosity.

from it not in kind but only in degree. Whenever inbreeding is practised, characters tend to separate out in the homozygous condition, and the closer the degree of relationship the more rapid will tend to be the process of segregation into pure-breeding strains. Continuous out-crossing, on the other hand, tends to keep a maximum of characters in the heterozygous condition, with a correspondingly wide range of possible combinations and a high degree of variability.

It must be pointed out that absolute purity of type, in the Mendelian sense, has probably never been reached with farm animals. In order to isolate "pure lines" from an ordinary mixed stock we should have to breed very closely for a considerable number of generations. In the case of full-brother-and-sister matings it might take some twenty generations. Nothing approaching this amount of inbreeding has ever been attempted in practice,[1] and so far we can only speak of strains of farm animals as relatively pure. Even in the most carefully selected and most closely bred families there must remain a considerable number of heterozygous characters. That this should be so, in spite of the obvious advantages of pure-breeding types, is accounted for by another phenomenon connected with inbreeding.

Very generally, when attempts have been made to inbreed through several generations, the breeder has found that his stock deteriorated in some respect—showed a lack of size, or vigour, or both; susceptibility to disease; lessened fertility, or perhaps complete sterility. The largest controlled experiment with cattle was carried out in the United States with Friesians. One section of the herd was "outbred," each successive herd sire being a carefully selected proven bull which was as nearly as possible unrelated to the females. The other half was closely inbred, each successive sire being a son or brother of his predecessor.

The conception rate was three services per pregnancy in the inbred section as compared with 1·9 in the outbred. The birth weight of the calves fell from 81 or 82 lb. in the first generation to 63·9 lb. in the sixth inbred generation. Mortality of calves was much higher among the inbreds than the outbreds. Milk yield

[1] A very high degree of uniformity is obviously required in laboratory animals, such as rats and guinea-pigs, which are used for the testing of the strength of drugs and the vitamin potency of foods. Some strains of these animals have been so much inbred that they seem to have reached the condition of pure lines.

was maintained for the first three generations of inbreeding but afterwards declined. The cows of the sixth inbred generation gave 31 per cent. less milk and 38 per cent. less butter fat than the original foundation cows.

When we mate two animals or plants, belonging to different inbred strains, the cross-bred progeny often show markedly greater vigour than either parent. This phenomenon is called "hybrid vigour" or *heterosis*. The theories that have been advanced to account for the facts—the decline in vigour under inbreeding and the gain when two inbreds are crossed—fall into two groups.

On the one hand it is argued that selection for economic qualities in an outbred population will quickly eliminate unfavourable dominant factors, whereas an unfavourable recessive, unless it is carried by a large proportion of the stock, will escape notice and will persist. When inbreeding is practised, however, the homozygous recessives will segregate out and, if their number is considerable or their effects severe, the strain will "degenerate." When we cross two unrelated (or only distantly related) inbred types the chances are that, with respect to the majority of factors, one or the other parent will contribute the favourable dominant, so that the cross-bred progeny will have few unfavourable recessive factors in the homozygous state. This theory appears to accord with most of the known facts. For instance, in the improvement of self-fertilized crop plants, the common procedure is to make a cross, to allow selfing for a number of generations, and to build up a new strain consisting of the progeny of a single homozygous plant. Such completely homozygous families may be of high economic value. Again, with certain laboratory animals—rats, mice, and guinea-pigs—inbreeding has been carried to the stage of almost complete homozygosity, but so far this has not been achieved in the case of any type of farm live stock, the reasons for the difference being probably that it is possible to keep small animals in relatively large numbers, that the generations are shorter, and that the higher level of prolificacy gives greater scope for selection. But it is also to be noted that many of the inbred families of laboratory rats, etc., are smaller and less prolific than the outbred populations from which they have been derived.

Another hypothesis, that does not exclude the last, assumes that "over-dominance" (or super-dominance) affects the influence

of certain genes—*i.e.* that a favourable dominant can be actually more effective in the heterozygous than in the homozygous state.

Whatever the theoretical explanation, it is clear that inbreeding does not lead to the creation of undesirable hereditary factors, but merely brings to light such as have been hidden. It does not lead, as was formerly supposed, to indefinite and progressive "running out"; deterioration comes to an end when the homozygous condition has been reached. Obviously, however, if the advantages of inbreeding, in the way of creating true-breeding types, are to be secured without the disadvantage of loss of vigour, etc., inbreeding must be accompanied by rigorous selection, so that, in practice, the degree of inbreeding that should be attempted must depend on the scope for selection. This, in turn, depends on the reproductive rate of the particular animal with which the breeder is concerned; for instance, there is far more scope for selection in poultry than in dairy cattle.

What is called "line breeding" is merely a less intensive form of inbreeding. The term is ordinarily applied in cases where the degree of kinship, between animals mated, is less close than that of full cousins. But statisticians, given an animal's full pedigree, can now place a numerical value on the degree of inbreeding. This expresses the percentage reduction, in the original number of heterozygous factors, that would be expected from the occurrence of particular ancestors at two or more places in the pedigree. It is rare to find, in ordinary pedigree herds, animals that are more than "10 per cent. inbred."

The most extensive experiments on the inbreeding of farm stock have been carried out with pigs under the auspices of the Bureau of Animal Industry of the United States Department of Agriculture.

Work on farm animals was preceded by pilot experiments carried out by Sewell Wright with guinea-pigs, which began in 1906. Of thirty-five original families, twenty-three survived. In all but one of these every mating was between full sibs (brother and sister), and in the one remaining family was between parent and offspring. In all cases there was selection of the best individuals from each litter. An outbred population was maintained as a control.

The inbred families, without exception, showed a decline in all the characteristics measured—adult size, growth rate,

prolificacy, etc., the most marked deterioration being in litter size. As would be expected, different families became differentiated in regard to coat colour and other characters. In the later years, crosses were made between representatives of different families, and all the cross-breds were markedly superior in every respect to either of the parent stocks.

This work suggested that the technique that has been successfully applied in the production of hybrid maize (see p. 251) might also be applied to live stock.

The pig-breeding investigation has been conducted on a very large scale. No less than 112 inbred lines were started, at ten different State Experiment Stations, in the thirties, and the work has been co-ordinated centrally since 1937. Up till 1953 some 14,000 experimental litters had been bred, and the number of experimental animals, in the herds, had reached about 1500. The main criteria in selection have been prolificacy of the sows, the viability of the piglets, growth rate, efficiency in food conversion, and carcass quality. Most of the foundation stock for the inbred lines was pure-bred, but some families were founded on first-cross or second-cross material.

The heritability of the desired qualities was found to be fairly low—averaging, for example, about 16 per cent. for litter size (numbers born).

Hereditary defects became prevalent in certain lines—*e.g.* hæmophilia (bleeding) and a high incidence of scrotal hernia—and the lines affected were discarded. Other families had to be abandoned owing to an extreme fall in prolificacy.

The intensity of inbreeding varied as between the various lines, most of the surviving families showing figures between 25 and 50 per cent.; but one line, produced by eight generations of brother × sister matings, had reached 80 per cent. inbreeding.

The average decline in prolificacy has been at the rate of about 0·3 pigs per litter for each 10 per cent. increase in inbreeding, but the variation as between families has been high.

None of the inbred lines, as such, is useful for commercial production, but performance is better in two-line and three-line crosses. Moreover, boars of certain inbred lines have proved very valuable for mating with sows of ordinary breeding, especially in cases where the boar and sow were of different breeds.

In general, the gain on crossing, in regard to useful qualities, has been greatest where the genetic differences between sire and

dam were at their maximum. The following figures show the average results obtained from crosses between an inbred boar and non-inbred sows of a different breed, as compared with those obtained by using a non-inbred boar of the same breed as the sows (*i.e.* ordinary pedigree breeding).

	Top Cross with Inbred Boar	Non-top Cross
Number of piglings farrowed .	9·85	8·69
,, ,, ,, weaned . .	7·64	6·56
Weight of litter at weaning . .	203·6	166·4

A special Association has been formed for the registration of animals belonging to the inbred strains. The most numerous of the new breeds is Minnesota No. 1, of which in 1952 there were some ninety herds comprising about 15,000 registered animals.

The tentative conclusion to be drawn from the American experience would seem to be that there are definite advantages to be gained by the systematic production of inbred families and the subsequent use of the inbred males for crossing, but that an immense expenditure, over a long period, will be required for the full exploitation of the system. The production of inbred stocks of Large White and Wessex pigs is in progress at the Animal Breeding Research Organisation, Edinburgh.

GRADING AND CROSSING

Where a breeder starts, as is often inevitable, with a collection of females of average or inferior quality he should normally endeavour to "grade up" his flock or herd by the continued use of pedigree sires. Obviously, before he begins operations, he should convince himself that one or other of the pure breeds will provide the type of animal he desires, and having once decided on a particular breed he should not lightly discard it for another. Certain of the Breed Societies encourage such grading by admitting to their registers "grade" animals with a certain proportion of non-pedigree ancestry. So long as the breeder is in the grading-up stage—*i.e.* so long as he is able to obtain from outside sources sires that are reasonably certain to improve the standard of merit in his herd—there is no particular advantage to be gained by close inbreeding; on the other hand, if he happens to secure a particularly good and impressive sire he should not hesitate to concentrate his "blood," and the experiment of mating him to his own

progeny will often be worth trying. A breeder who is grading-up may study pedigrees with just as much advantage as the pedigree breeder himself, for if he is content to buy any registered sire on his appearance alone he may get an animal of mixed or inferior ancestry that may bring him serious loss.

Cross-breeding, so long as it is carried out systematically, has, for the production of "commercial" animals, certain definite advantages over pure-breeding. Cross-bred animals commonly show the phenomenon of *heterosis* or hybrid vigour—that is to say, are more prolific and more resistant to disease and grow more rapidly than pure-breds. Theoretically, of course, it is possible to collect a complete set of desirable dominant factors in a single homozygous strain, but many generations must elapse before this can be accomplished with farm animals. Meantime, such valuable dominants as have been fixed in two breeds can be combined by crossing. Heterosis is usually most marked in the first cross; hence cross-breeding should not be carried beyond this stage or, at the most, beyond that of mating a first-cross female with a pure-bred male. In the latter case the disadvantage of irregularity in the second-cross generation may be outbalanced by the advantages of hardiness and prolificness in the cross-bred dams.

In practice cross-breeding offers the greatest advantages in highly prolific species like pigs and poultry, because in these cases a relatively small proportion of pure matings will suffice to produce the necessary supply of selected pure-bred females. In the less prolific species a large proportion of the females born must be kept for breeding, and widespread crossing involves the retention either of cross-bred females or of inferior pure-breds. In the case of dairy cattle, crossing is very liable to degenerate into "mongrelizing," because the cow must breed in order that she may milk. Normally, grading is the better system to pursue in dairy herds.

It is a common misconception that inferior pure-bred sires are good enough for crossing. It is true, of course, that there is a limit to the sum of money that can be profitably invested in a crossing sire, and it is also true that animals which are faulty to the eye of the pedigree breeder may be excellent from the point of view of the commercial breeder. But it is only by careful selection of his sires, and by careful study of his results, that the cross-breeding farmer can hope to repeat his successes and avoid recurrence of his failures.

CHAPTER II

THE PRINCIPLES OF NUTRITION

A CONVENIENT approach to the study of the nutrition of farm animals is to consider the various chemical compounds which are contained in feeding stuffs and the uses to which they are put in the animal body. The many hundreds of chemical compounds in feeding stuffs are classified by chemists into four major groups. These are: (1) Mineral or ash constituents; (2) the nitrogen-containing constituents; (3) the fatty and waxy materials; and (4) the carbohydrates. This classification is a very general one, and each major class contains a multitude of compounds; indeed, the chemical constitution of some is not exactly known. One very important component of feeding stuffs has, however, been left out of the above classification, namely, water. The first step a chemist takes in the analysis of a feeding stuff is to determine its moisture-content by heating it at the boiling-point of water. He then determines the amount of the other major classes of material in the dry matter. Even the so-called dry feeds contain water. Freshly purchased concentrate cubes contain the least, namely, about 10 per cent.; hays and straws about 10 to 15 per cent.; grass and green forages between 65 and 85 per cent. The highest water-contents are found in turnips and swedes, which often contain over 90 per cent. A high water-content, of course, increases the cost of handling and transporting a crop, but at the same time succulent foods such as green crops, roots, and silage appear to have a special value which cannot be simply accounted for. A good supply of water for all farm stock is essential, because water is constantly being used to excrete, in solution in the urine and fæces, unwanted waste products arising from the breakdown of food materials in the body. A further loss of water occurs through the skin and in the breath of the animal; in fact, a highly fed dairy cow will lose as much as 4 gals. of water per day by evaporation. In the breakdown of food some water is formed in the body, but this amount goes only a small way to meet these losses. Water requirements of stock are met not only by drinking water but also by the water contained in their feed. In the

spring, for instance, heifers grazing on lush pasture receive sufficient water from the herbage they consume, and do not go to the drinking trough. The same is true of sheep which on fresh pasture drink no water, but on old pasture, in dry weather, may drink up to half a gallon per head per day. The following table summarizes the normal water intakes by farm animals. With the exception of young calves, which never know when they have had enough, and fattening pigs, where a convenient rule is 3 lb. of water to 1 lb. of meal, farm animals are best left to judge their own requirements, and unlimited water should be made available.

Water Requirements on Dry Rations

Class of Stock	Weight (lb.)	Water required per Day (lb.)
Weaning calves	150	10 to 15
Dry cows	1000	70 ,, 80
Milking cows *	1000	Up to 180
Sheep	150	,, 10
Weaning pigs	30	4
Baconers	200	8
In-pig sows	400	10 to 12
Suckling sows	300	40 ,, 50

* The milking cow requires 1½ to 2 gals. of water for every gallon of milk she produces besides that which she would need if she were dry.

Minerals.—The ash constituents of feeding stuffs are determined by incinerating the dry material at a dull red heat in a furnace. The unburnt residue consists of silica and the sulphates, chlorides, phosphates and carbonates of calcium, magnesium, potassium, sodium, iron, and a large number of other elements. Some of these others, like copper and cobalt, are of considerable nutritional significance. Others, like boron, aluminium, and nickel, while known to be present in minute amounts in animal tissues, do not appear to be essential. The amount of ash in feeding stuffs varies considerably. Some feeds, such as flaked maize, contain very little indeed—less than 1 per cent.—while feeds such as fish meal contain more than 20 per cent. Most common feeds contain from 2 to 8 per cent. of ash, calculated on a dry-matter basis.

All animals require minerals, and some of these must be given in organic form. Thus the animal must receive at least part of its sulphur requirements in the form of the sulphur-containing amino acid methionine. Some mineral elements are toxic when

given in large amounts. Thus common salt may easily poison poultry and pigs if inadvertently they are given doses too large in relation to their water supply. Again, cattle which have access to pastures which have received heavy dressings of phosphate fertilizers and have not been washed by rain may suffer from scours for a day or two. Some minerals are toxic even when only very small amounts are supplied. Molybdenum, which is present in the herbage of certain pastures in Somerset—the so-called "teart pastures," causes severe scouring in cattle. Luckily, the trouble may be prevented by giving cattle a special cake containing copper. Selenium is responsible for a disease of cattle in certain parts of Ireland and the United States. In this case, unfortunately, there is no antidote to the disease and, since selenium is present in the soil of the areas and in all crops grown thereon, it is impossible to carry on any system of live stock husbandry without running the risk of serious loss. Poisoning by fluorine, which may contaminate pastures through flue gases and industrial smoke from certain modern industries, produces widespread abnormalities of the bones and teeth of cattle and has caused many deaths in several areas of Britain. Of all toxic elements, lead is probably the most important in practice. Every year in Britain many hundreds of calves die as the result of chewing the lead-painted doors of their boxes.

Though certain minerals can cause ill-health or even death, much more harm to the productivity of live stock results from a shortage, in their daily rations, of essential minerals. Of these, calcium and phosphorus are of supreme importance. About 75 per cent. of the total ash of the body of farm animals consists of these two elements. Together they make up 99 per cent. of the ash of the bony skeleton, and phosphorus is also contained, in appreciable amounts, in the soft tissues. It is thus the rapidly growing young animal, which is laying down both soft and skeletal tissues, that has the greatest need for these elements. But milking animals also have a great need, since a gallon of milk contains about $\frac{1}{8}$ oz. calcium and $\frac{1}{8}$ oz. phosphorus. These amounts must therefore be supplied in the feed. But during early lactation the milking cow draws part of the requirements from her own bones and, later in lactation, rebuilds her depleted bones in preparation for her next lactation. A shortage of calcium and phosphorus leads to rickets and other bone abnormalities. The soils of some large areas, notably in South Africa, are by nature grossly deficient

in phosphorus, and the natural herbage is so deficient that cattle grazing it develop the disease "aphosphorosis," which is characterized by a stunting of growth and a depraved appetite. Mild forms of this deficiency disease have been seen in Britain, and it has recently been suggested that shortages of phosphorus, or an imbalance of calcium and phosphorus, may lead to infertility in dairy cattle.

In meeting the requirements of animals it must be remembered that most concentrates are low in calcium, and that some starchy feeds are very poor in phosphorus as well. The usual home-grown mixtures for milk production are generally deficient in calcium, phosphorus, and common salt, so that a proprietary mineral mixture or (more cheaply) a mixture of two parts common salt, one part ground chalk, and one part sterilized bone-flour should be added to the concentrate ration at the rate of 3 lb. minerals per cwt. Attention to the calcium and phosphorus supplies of pigs is also essential when these are kept and managed under intensive conditions. If the ration is reasonably good the addition of 1½ per cent. ground chalk and 1 per cent. common salt will suffice.

Trace Minerals.—Animals that are living under natural conditions, *e.g.* on normal good pasture, are almost certain to receive sufficient mineral nutrients; but if the soil is seriously deficient in a particular mineral, deficiency disease will appear in the grazing animals. Disease will also occur in animals maintained on the conserved forage, in the absence of a supplementary source of minerals. One example is "pining" or "moor sickness" in sheep, which occurs on many hill grazings in Scotland and Wales and in certain parts of England also. Sheep confined to these hills or moors lose appetite and become anæmic and weak. The disease is due to the absence from the soil, and hence from the herbage, of the minute amount of cobalt which is necessary to the well-being of ruminants. The amount needed by the sheep is extremely small—about 1 part in 10 million of its food. Copper deficiency also occurs on some soils and results in a pining condition, or in scouring and unthriftiness, in cattle. In the pregnant ewe shortage of available copper results in her giving birth to lambs with "swayback." Such lambs may be unable to stand, or can stand and walk only unsteadily, with a characteristic swaying of the hind quarters. In certain parts of Britain (notably in Derbyshire) these conditions occur even where

the copper-content of the soils appears to be normal, and it is thought that the presence of other minerals in the herbage may make the copper unavailable. A further trace element deficiency which occurs in farm practice is that of iron and copper together. These elements are needed for the manufacture of hæmoglobin, the red pigment in blood cells. Sows' milk is grossly deficient in these elements, so that sucking pigs that are reared indoors often become anæmic and may die. Dosage with a solution of iron and copper both prevents and cures the disease. Piglets running out of doors can obtain iron by rooting in the soil and are therefore rarely affected. Deficiencies of manganese and iodine have also been known, but only rarely, to occur in farm live stock in this country.

In general, shortage of trace elements is rather rare, occurring only over a very small range of soil types or under highly artificial systems of intensive rearing. Provided that sufficient calcium, phosphorus, and common salt are present in mixed rations and that a fair variety of feeding stuffs is used throughout the year, there is seldom any danger of deficiencies of the other mineral elements.

The Nitrogen-containing Constituents.—Returning to our broad classification of the constituents of feeding stuffs, we come to those which contain nitrogen. These include a vast number of different substances, some being of fairly simple constitution, while others are of very great complexity. The most important members of this latter class are the proteins, such as the casein of milk, the albumen of egg-white, and gluten, one of the main proteins of wheat grain. Sometimes this whole class of nitrogen containing nutrients is referred to as *crude protein*, and a distinction is made between the actual or *pure protein* and the remainder, sometimes termed "*amides*" but more correctly, *non-protein nitrogen-containing substances*. *True proteins* contain some 15 to 17 per cent. of nitrogen and are of exceedingly complex composition. When broken down, an individual protein may yield up to twenty or more relatively simple compounds called *amino-acids*. Of these twenty a proportion can be manufactured in the body from quite simple forms of organically combined nitrogen, but ten of them, the so-called *essential amino-acids*, have to be provided in the non-ruminant animal's diet in order that it may be able to build up its own body proteins, those of eggs and of milk and the keratin proteins of hair. The non-proteins

of feeding stuffs include firstly amino-acids and amides, and (in smaller amounts) alkaloids, lecithins, betaines, and many other simple crystalline materials. While some of these simple compounds can be used or broken down by the animal, it is only the amino-acids, whether derived from the proteins or from the non-protein fraction, that are essential.

The proportion of the crude protein which is in the form of pure proteins varies greatly from one feeding stuff to another. In ripe seeds it is commonly more than 90 per cent., while in mangolds it is only about 10 per cent., the remainder, in this case, including some nitrate. In rapidly growing green crops, in which the manufacture of protein is proceeding, as much as 50 per cent. of the nitrogen is represented by non-proteins such as the amides asparagine and glutamine. The total content of crude protein also varies widely; for instance, cereal straws contain only 1 or 2 per cent., beans and peas about 25 per cent., and some oil cakes contain more than 40 per cent.

In the digestion of protein-containing feed by simple-stomached animals such as pigs, the enzymes of the digestive tract break down the proteins to amino-acids. These are absorbed into the blood stream and are later reassembled in the tissues to produce the specialized proteins of muscles, liver, hair, milk, and so on. The proteins vary in composition, yielding various proportions of the common amino-acids. Some proteins fail to yield particular amino-acids; for example, gelatine, from bones, yields none of the amino-acid tryptophan, while gliadin, from wheat grain, yields no lysine and very little tryptophan. Information is scanty but it is known, for example, that the proteins of the pulses tend to be low in lysine, and that the best of all, from the point of view of amino-acid make-up, is the mixed proteins of whole egg. If the pig be given an otherwise adequate ration, with gelatine as the only protein, it fails to gain in weight because of the lack of the essential tryptophan. Again, if given a diet with wheat proteins as the sole source of protein, its growth rate will be low because of a shortage of lysine. The pig, in reassembling the amino-acids derived from its food, is limited by the supply of each individual one. Those which it cannot use are broken down in its liver, the nitrogen being converted first to ammonia and then to urea, which is excreted in the urine. The carbon-containing residue can, however, be used as a source of energy and, in part, stored as body fat.

Food proteins thus differ widely in their ability to produce body gains in the pig and other simple-stomached animals. The degree of efficiency of utilization of a protein is usually expressed as its *biological value*. Proteins with a biological value of 100, such as those of whole egg, are such as can be utilised by the animal without wastage. A protein such as gelatine, when fed by itself, can hardly be used at all, and has a biological value of about 25. The proteins of cereals are about 70 per cent. as good as whole-egg protein, while those of skimmed milk are nearly as good, having a biological value of over 90. In general, animal and fish proteins, such as those of blood meal, meat meal, and white-fish meal, are much superior to plant proteins as sources of essential amino-acids. It is broadly true that a mixture is better than any single protein, since a deficiency of a particular amino-acid in one protein is often balanced by an excess in another. For example, better growth is obtained if an all-cereal ration, which is deficient in lysine, is supplemented with gelatine, which yields a large amount of lysine. This is true despite the fact that gelatine provides none of the essential tryptophan. The biological value of the protein is unlikely to be a limiting factor in the growth of pigs and poultry if mixed rations are employed, particularly if, as is usual, some fish meal or other animal protein is included in their rations.

With pigs and poultry it is quite certain that the amino-acid composition of the food protein is important in relation to growth. By contrast, the importance of biological value to ruminants is much less.

In the ruminant all food first enters the capacious paunch, which can be described as a fermentation vat. Here vast numbers of micro-organisms break down the proteins into their constituent amino-acids and indeed often beyond this point. Simultaneously they rebuild the fragments into their own body proteins. The partly fermented food mass, containing the bacteria, then moves down the digestive tract where the proteolytic enzymes hydrolyze not only the food proteins which have escaped ruminal fermentation, but also a proportion of the bacterial proteins as well. Thus the cow and the sheep assimilate not only the mixture of amino-acids supplied in their food, but also the complex mixture which is the product of bacterial action in degrading and synthesizing amino-acids from those provided by, or derived from, the non-protein nitrogenous compounds of the feed. The

ruminant is indeed able to utilize quite simple nitrogen compounds, such as urea and ammonium salts, as a partial substitute for protein, the explanation being that the bacteria can use these to manufacture amino-acids. It is thus clear that, for ruminants, the biological values of proteins have only a limited significance; first-class proteins tend to be degraded and poor proteins to be up-graded, so that only small differences in growth, protein storage, or protein synthesis by the animal result from widely different forms of nitrogen compounds. There is, however, strong evidence to the effect that the rumen bacteria are not capable of providing the ruminant with all the amino-acids it needs. In particular, they are not very efficient in the manufacture of the sulphur-containing amino-acid methionine, and it is improbable that they can provide certain particular amino-acids in amounts adequate to provide for a high level of milk production. Some early experiments certainly suggest that a shortage of lysine in the ration can cause a fall of milk yield.

The facts set out go far to explain the observation that dairy cows show very little response, in milk yield, to major changes in the make-up of their food protein, and suggest that, for ruminants, the non-protein nitrogen fraction of feeds has a value but little short of that of true protein. In British feeding standards some cognizance is taken of these facts by ascribing to the digested non-proteins half the value of pure proteins; the sum of the digested pure protein and half the digested non-proteins is called the "protein equivalent." A sample of swedes, for instance, might contain 1·2 per cent. of digestible crude protein, consisting of 0·2 per cent. of digestible true protein and 1 per cent. of digestible non-proteins. The protein equivalent of swedes would thus be $0{\cdot}2+\frac{1{\cdot}0}{2{\cdot}0}=0{\cdot}7$ per cent. It would seem, however, that the protein value of foods for ruminants would be better measured by the total figure for digestible crude protein, without correction.

The Fats.—The next large group of food constituents are the fats. These, as determined by the standard method of analysis, include not only the true fats or glycerides, but resins, organic acids, essential oils, sterols, and plant pigments such as chlorophyll and the carotenoids. All these constituents are extracted from the dry, finely-ground feeding stuffs by prolonged treatment with hot ether, and hence they are more correctly known as "ether extractives." In some foods, such as linseed,

the glycerides account for the larger part of the ether extractives, while in others—notably the straws and hays—the non-glycerides are the more abundant. In general the glycerides have a much greater feeding value than the non-glycerides, but the latter fraction includes certain very important compounds, notably vitamins A, D, and E, which, as we shall see later, are of paramount importance in nutrition.

The Carbohydrates.—The carbohydrates of feeding stuffs are generally classified as follows :—

1. *Monosaccharides*, or simple sugars, such as grape sugar and fruit sugar, which are hexoses with the general formula $C_6H_{12}O_6$ and the pentoses with the general formula $C_5H_{10}O_5$.

2. *Disaccharides*, which include cane or beet sugar, milk sugar, and malt sugar, and have a general formula $C_{12}H_{22}O_{11}$.

3. *Polysaccharides*, which make a very large group of compounds, all of which have a high molecular weight and may be regarded as complex condensations of the simple sugars. They include starches, which are the reserve materials found in many plants, and dextrins, the simpler compounds which arise during the build-up or breakdown of starch. In digestion by animals with simple stomachs (pig and fowl) nearly 100 per cent. of the starches, dextrins, and disaccharides are hydrolyzed to simple sugars by the action of enzymes secreted into the digestive tract. These simple sugars are then absorbed into the blood stream. The other important group of polysaccharides are those which are generally known as "cell wall constituents" or, more loosely, as "fibre." They include a very large number of compounds—pectins, cellulose, lignin, hemicelluloses, pentosans, and polyuronides. Of these, the most important are cellulose and lignin. Cellulose is a major component of cell walls and is a polymerized glucose, yielding glucose on hydrolyzation. However, none of the enzymes produced by the wall of the digestive tract can carry out this hydrolysis, and thus simple-stomached animals cannot digest cellulose. But the immense number of bacteria which are present in the rumen of cattle are able to break down cellulose and, in doing so, supply their host with a source of food it could not otherwise obtain. A little fermentation of the same type does take place in the cæcum of simple-stomached animals, accounting for the small amount of cellulose which is apparently digested by these species. The product of the fermentation in the ruminant is not, however, glucose. When cellulose is

fermented by the cow, the gas methane is formed and simple fatty acids, notably acetic, are produced as well. Some of the cellulose is converted into bacterial starch in the bodies of the organisms, and some of the energy locked up in the cellulose is liberated as heat. Hence the ruminant does not obtain the whole of the energy of the cellulose which the bacteria break down. The gas methane is of no value, the heat produced being often (though not always) a burden rather than an advantage, while some of the bacterial starch may probably escape digestion in the lower part of the digestive tract. The ruminant can, however, utilize the lower fatty acids, and experiments have clearly shown that these can be directly incorporated into milk fat. The bacteria can also attack starch and the simple sugars contained in the diet.

The other important cell-wall constituent, lignin, is not attacked by bacteria at all, nor is there any digestive juice which can break it down. Lignin is thus completely inert. This is of very great importance in the feeding of live stock, since as plants get older lignin is laid down on top of the cellulose layers in order to give rigidity to the stem, leaf veins, and seed coat. This process of lignification makes the plant less nutritious because the cellulose and the cell constituents are protected by the coating of lignin from the action of the bacteria. Lignification accounts for the decline in the digestibility of hay when cutting is delayed.

The usual way of measuring the amount of woody fibre, *i.e.* lignified cellulose, is to boil the ground material first in dilute acid and then in dilute alkali. The insoluble residue is called "crude fibre." This represents only a rough approximation to the lignin and cellulose content, because lignin is partially soluble in the alkali and cellulose partially soluble in the acid. Thus "crude fibre" from a late-cut hay or a straw is very different, in terms of nutritive value, from the "crude fibre" of young spring grass. The latter is extremely well digested by cattle and sheep but the "crude fibre" of straws is not. The chemical method of estimating the other carbohydrates is even more unsatisfactory. They are calculated by difference, *i.e.* the sum of the ash, nitrogen-containing materials, ether extractives, and crude fibre is deducted from the total dry matter. The difference is called "carbohydrates" or, more correctly, "nitrogen-free extractives." *No entirely satisfactory scheme of analysis for true carbohydrates has yet been devised.* The best available measure

of the value of the total carbohydrates of a feed is obtained by feeding experiments in which the digestibility of the crude fibre and nitrogen-free extract is determined.

The Vitamins.—In 1906 the late Sir Frederick Gowland Hopkins stated that " no animal can live on a mixture of pure protein, fat, and carbohydrate even when the necessary inorganic material is supplied." From his own experiments and others Hopkins concluded that some other substance or substances were required. These were first called " accessory food factors " and, later, vitamins. To-day there is an immense amount of knowledge not only about their chemical structure but also their physiological effects both on laboratory rats and guinea-pigs and on farm animals and man. The vitamins are classified as either fat-soluble or water-soluble. The fat-soluble group includes vitamins A, D, E, and K, and the water-soluble group vitamin C and the numerous members of the vitamin B complex.

Fat-soluble Vitamins.—*Vitamin A* is a colourless substance of known chemical constitution which is found in the liver oils of fish and animals. It is formed in the animal body largely from the orange-yellow beta carotene, one of the several yellow pigments called carotenoids associated in the plant with the green colouring material chlorophyll. β-carotene is indeed not the only precursor of vitamin A. Yellow maize grain contains crypto-xanthine which is also a precursor of vitamin A. But β-carotene is the most common. All animals have the power of converting carotene into vitamin A, but some do so more efficiently than others. Thus the Guernsey cow produces a yellow milk fat because she passes into her milk a considerable portion of the carotene she ingests. The Ayrshire, on the other hand, given exactly the same ration, converts more carotene into vitamin A before secreting it. The goat secretes no carotene in her milk. Despite the difference in colour the values of these milks in preventing disease due to vitamin A deficiency can be the same. No animal can manufacture vitamin A in its body except from the precursors, and the vitamin A potency of eggs and milk is directly proportionate to the amount of carotene which the hen or the cow obtains from its food.

As would be expected, carotene is largely found in green, leafy materials. Seeds and common farm concentrates contain very little, even yellow maize being a rather poor source. Carrot roots are very rich in carotene but mangolds, swedes, turnips,

sugar-beet pulp, and potatoes supply practically none. Some fish meals contain a little pre-formed vitamin A, but the small amount is sometimes lost during processing. The green leaf is the main and the richest source, and the carotene-content falls markedly as the plant matures.

Carotene is not very stable and is rapidly destroyed in the presence of oxygen. Carotene in cut grass is thus largely destroyed in the common process of hay-making, and it is only if the hay retains a good green colour that it can be regarded as a highly potent source. The table shows the original carotene-content of a crop of grass and indicates the losses which occur when it is conserved in different ways.

Material	Carotene-content of Material on a Dry Basis, mg. per 100 g. (Parts per 10,000)
Fresh grass	30
Hay made with little weathering	8
Hay, badly weathered	4
Ensiled	20
Artificially dried	26
Hay, badly weathered, after storage for two months in bales	1

Artificial drying is clearly the best method of conservation from the point of view of conserving carotene. Bales of dried grass, however, gradually lose their carotene-content through oxidation, this being particularly noticeable on the outside layers. Under most circumstances, dried grass of high quality is the best source of the vitamin. Cod-liver oil, which supplies pre-formed carotene, has been much used in the past, but when mixed with feeding stuffs its vitamin A value falls off very rapidly, complete destruction occurring within about three weeks. Moreover, under some conditions cod-liver oil is now known to have bad effects on animals. It is therefore generally advisable to rely on young green material for meeting vitamin A requirements.

To ensure an adequate supply, it is necessary for the farmer to maintain a supply of fresh, leafy green stuff such as kale, clover, lucerne, or grass throughout the year, and to have a reserve of high-quality silage or dried grass. Foods that are rich in the vitamin need be given only in small amounts. Three ounces of really young leafy grass will meet the daily requirements of a growing pig and 2 to 3 lb. those of a milking cow.

During the summer and autumn, when greenstuff is plentiful,

animals are able to store both vitamin A and carotene in their livers and are able to fall back on these stores during periods when their diet is deficient in the vitamin—*e.g.* is composed largely of mangolds, straw, corn, and cake. Thus, if a calf, which has been running with its dam on pasture, is brought indoors in autumn and is given a ration completely free of the vitamin, it will have sufficient reserve to last for at least five months. Similarly, a pig, given a single large dose of vitamin A concentrate at weaning, will store enough in its liver to last it until it reaches bacon weight. In milking animals, however, there is a steady drain on the reserves, and these are much more rapidly exhausted. This does not mean that the cow will show symptoms of deficiency; in fact, it is necessary to feed a cow on carotene-low rations for well over a year before failure of reproduction and the general breakdown occurs. She may, however, give birth to a weak or dead or blind calf before she has begun herself to show symptoms of deficiency.

Young animals, in general, are born with very small reserves of vitamin A in their livers. Moreover, they appear to need more of the vitamin, in relation to their body weight, than do older ones; but they obtain a large amount of the vitamin from the colostrum of their dams, which is a much richer source than full-lactation milk. The vitamin A potency of colostrum—due both to preformed vitamin A and to carotene—is influenced by the carotene-content of the ration which the animal receives during pregnancy. Thus, after a long winter in which rations low in carotene-content have been fed, the colostrum will have a low vitamin A value. It will thus be clear that the proper feeding of cows during pregnancy is of great importance from the point of view of the health and viability of the calf.

Vitamin A deficiency in young cattle is not uncommon in this country. The main signs are failure to thrive, night blindness, and, later, total and incurable blindness due to damage to the optic nerves. In pigs, vitamin A deficiency leads to paralysis of the hind quarters and a staggering gait. In chicks, growth is retarded, the birds become weak and emaciated, and the membranes of the mouth become thickened and pustular. The eyes, too, are often seriously affected. In all animals secondary bacterial infections occur where the deficiency is prolonged, and these may lead to the death of the animal. In this connection there is a great deal of evidence to suggest that many calves,

in late winter, have subnormal reserves of vitamin A, and it is possible that the high incidence of scours, pneumonia, and other transmissible calf diseases at this season may be accounted for by shortage of vitamin A.

Vitamin D was first identified as a substance, present in cod-liver oil, which was essential to the prevention of rickets. Vitamin D is, in fact, often called the anti-rachitic factor. It is now known that a number of plant and animal sterols, when exposed to the ultra-violet rays of sunlight, become potent as vitamin D. In all, there are at least ten different forms of vitamin D, the most important being vitamin D_2 (the form found in plant products such as sun-cured hay and irradiated yeast) and vitamin D_3, which is found in animal products, notably in fish oils, and indeed is formed in the animal body itself during exposure to ultra-violet light. The distinction between vitamins D_2 and D_3 is important because, while both have the same anti-rachitic value for the laboratory rat and other species, vitamin D_3 is far more effective than vitamin D_2 for poultry. Fish oils and irradiated animal sterols are thus much better sources for poultry than are irradiated plant materials.

Vitamin D itself is very sparsely distributed in animal feeding stuffs, but the sterols are fairly widely distributed. Fresh green foods contain very little vitamin D. For example, in rapidly growing pasture grass it is only small dead areas of leaf, which have been irradiated by the sun, which contain any. For the same reason artificially dried grass, not having been exposed to the sun, has a very low vitamin D content. On the other hand, sunshine and "sky-shine" irradiate the skins of animals running out of doors, and hence produce in them a supply of the vitamin. The problem of vitamin D deficiency thus concerns animals which are kept indoors and do not receive sun-cured foods. In this connection it should be noted that ordinary window glass does not allow the short wave-lengths of ultra-violet light to pass through it; and hence, though a building may be well lit, the glass-filtered light will not prevent rickets. Glass substitutes are, however, available which, provided they are kept clean, admit the ultra-violet light.

Unlike vitamin A, vitamin D is not very easily oxidized; in fact, vitamin D was discovered by bubbling oxygen through cod-liver oil, thus destroying vitamin A and leaving the vitamin D unimpaired. The vitamin D activity of hays does not therefore

decline during storage, nor does the activity of vitamin D concentrates deteriorate when they are mixed with other feeds.

Rickets, the disease due to vitamin D deficiency, is characterized by a failure of the animal to lay down calcium and phosphorus in its bones. The cartilaginous material is not calcified, the bones become rubbery, so that bent and malformed limbs result. Rickets can, however, occur as the result of a deficiency of calcium or of phosphorus in the diet, and it is necessary to the understanding of bone growth to consider calcium, phosphorus, and vitamin D together. When the ratio of calcium to phosphorus is abnormal, then vitamin D will often permit normal growth, whereas if the ratio is optimal it may be very difficult to demonstrate any requirement for vitamin D. Vitamin D is not a substitute for calcium and phosphorus, but it enables growth to take place under dietary conditions which would otherwise soon result in unsatisfactory bone formation. Hens given rations low in vitamin D produce fewer eggs of lowered hatchability, and the few eggs that are laid have very thin shells. In chicks, rickets is very common and can be recognized by the ungainly attitudes that affected birds adopt to balance their bodies, and by their lame, stiff-legged gait. The breastbone is often bent and the beak becomes soft, rubbery, and easily deformed.

Vitamin E, when first discovered, was found to be a dietary ingredient essential for the reproduction of the rat. Without it male rats developed permanent sterility, and in pregnant females the embryos degenerated and were reabsorbed. Experiments and practical tests have shown that with cattle, sheep, and goats vitamin E is apparently not concerned with reproduction. Pigs may require it for normal reproduction, and it is known that adult birds, if deprived of it, produce eggs which have a low hatchability.

Though not concerned with reproduction, the vitamin is nevertheless of importance in farm animal nutrition. Under certain conditions associated with rations low in vitamin E content, cattle and sheep develop a muscular disease called muscular dystrophy or "stiff-lamb disease," while poultry develop severe nervous and circulatory disturbances. All these diseases have been found to occur on farms in Britain where inadequate rations were given. One important aspect of the disease in calves is that it follows dosing with cod-liver oil. Though cod-liver oil supplies vitamins A and D it contains

unsaturated fatty acids which increase the animal's vitamin E requirements as much as fifty-fold. Small amounts of most proprietary concentrates of vitamins A and D do not have this effect. Vitamin E is found in large amounts in green foods and, as with vitamin A, the chief danger of deficiency is in young animals born in the later winter to dams which have received poor rations throughout a considerable time.

Vitamin K is concerned with the maintenance of the clotting time of the blood. An animal deficient in this factor may bleed to death from a minor wound. The vitamin was discovered in experiments with chicks. In parts of North America deficiency of vitamin K occurs when cattle eat mouldy *Lespedeza* hay. The symptom in cattle is due to poisoning by the substance dicoumarol which is present in the moulded hay and which acts as an anti-vitamin K. Deficiency of the vitamin has not been recorded as a cause of losses in Britain.

The Water-soluble Vitamins.—*Vitamin C* is required only by guinea-pigs, humans, and the higher apes, where a lack causes scurvy. Farm animals and birds manufacture the vitamin in their systems.

Vitamin B Complex.—The remaining water-soluble vitamins are all grouped under this one name, and in the last twenty years the number of members of this group has grown to twelve. There are probably others yet undiscovered. No member of the vitamin B complex is required by adult ruminants, the reason being that the micro-organisms of the rumen, besides transforming food proteins and breaking down the fibrous constituents of feeds, manufacture the vitamins of the B complex in sufficient amounts to meet the need of their host. Before the rumen of the young animal is fully established—*i.e.* while it is eating no solid food—it needs a source of these B complex vitamins in its ration, but once the rumen flora is established the need comes to an end. Recent experiments have shown that horses do require some members of the vitamin B complex, but it does not appear likely that practical rations would ever be deficient. Hence pigs and poultry, and the farm dog, are the only farm animals which are ever likely to suffer from major deficiencies.

Some of the individual members of the vitamin B complex are given in the table opposite, which summarises all that was known, at the time of writing, about their essentiality in the rations of pigs and poultry.

The Vitamin B Complex

Vitamin	Other Names	Chief Signs of Deficiency as observed in Experiments		Agricultural Importance
		Pigs	Poultry	
Aneurin	B_1	Loss of weight	Nervous disease (polyneuritis) causing abnormal posture	Very little importance, since cereals and millers' offals are rich in the vitamin
Riboflavin	B_2	Limb stiffness	Curled toe paralysis of chicks	Of importance for baby chicks which should receive some riboflavin supplement such as dried whey or dried skimmed milk if given simplified rations
Nicotinic acid	PP factor (Pellagra preventive)	Severe diarrhœa and loss of appetite	Inflammation of the mouth and darkening of the tongue	Deficiency has occurred in farm practice where rations are restricted to maize and maize products; but lack of the vitamin unlikely in normal practice
Pyridoxine	B_6	Anæmia and fits	Convulsions	Deficiency in ordinary rations unlikely
Pantothenic acid	...	Nervous disturbances and "goose-stepping"	Failure of growth	Very unlikely to be absent from common farm rations
Biotin	...	Cracked hooves	Poor growth and skin disorders	Very unlikely to be deficient in farm rations
Choline	...	...	Hock disorder called "perosis"	Unlikely to be deficient in farm rations
Folic acid	...	Anæmia	Anæmia and poor feather development	Very unlikely to be deficient in farm rations
B_{12}	...	Anæmia and poor growth when restricted to rations containing vegetable proteins only	Anæmia and poor growth when restricted to rations containing vegetable proteins only	Of importance as a constituent of the animal protein factor

These requirements have been established by experiments in which highly artificial rations were fed—composed of highly purified feeds, such as raw starch and glucose. These experiments, while they have established that the pig and chick require these members of the vitamin B complex, give no indication of their importance under practical conditions of husbandry. In general, deficiencies of vitamins of the B complex in pigs and poultry are rare, though "curled-toe paralysis" and "perosis" in poultry do appear occasionally. The former is due to a deficiency of riboflavin in the ration, and for best results starting mashes for chicks should contain 5 to 10 per cent. dried whey, or dried skim-milk powder, which are rich in riboflavin.

Considerable attention has been paid recently to the so-called "animal protein factor." At the date of writing it appeared that this was not a single "A.P.F." but several distinct factors, including vitamin B_{12}. "A.P.F." is found associated with protein in feeding stuffs derived from animals but is absent from those derived from plants. It appears that the poor growth of pigs and poultry restricted to rations containing only plant proteins is in part due to deficiency of this factor, and that the addition of A.P.F. concentrates makes such rations as good as those containing fish meal, meat meal, or milk. In Britain, as the result of long experience, it has become a usual practice to incorporate fish meal into most rations for rapidly growing pigs and poultry; hence deficiencies of A.P.F. arise only infrequently.

Closely associated with the A.P.F. is the discovery that antibiotics such as penicillin and aureomycin promote growth. The increase in live-weight gain may result from the control, by the antibiotic, of very slight and perhaps imperceptible "infection" of the animals which respond. This "infection" has been transmitted from bird to bird but its nature at the time of writing was unknown.

Food Requirements.—From what has been said it will be clear that animal nutrition is a very complex science. An animal requires in its food some eight or ten essential amino-acids, about fifteen vitamins, and about the same number of essential mineral elements, as well as carbohydrates and fats as sources of energy. Ruminants, by virtue of the activity of their rumen flora, can dispense with some of these nutrients.

Of all these many requirements the one which is of primary importance is energy. It has been estimated that by far the

main part of the economic loss that is due to faulty nutrition of farmstock results from failure to meet the animals' energy requirements. These are usually divided into maintenance and production requirements. The requirement for maintenance is the amount that the animal must expend on the various processes and reactions of the body which are essential to life. An animal is thus very unlike an internal-combustion engine. When the latter is not being used it does not require fuel. When a milking cow is dry or when a steer is not growing, or fattening, it still requires a source of energy to keep it "ticking over." The production requirement is the amount of energy which the animal needs, in addition to its maintenance demand, to support the production of milk, eggs, meat, or fat, or to meet the energy lost to the body in muscular work.

Energy requirements are measured in terms of Calories, one Calorie being the quantity of heat energy which is required to raise the temperature of 1 kg. of water 1° C. It is written with a capital C, or called the kilogram Calorie, to distinguish it from the "calorie," 1000 of which make up the kilogram Calorie. A thousand kilogram Calories make one therm.

The total or *gross energy* value of a feeding stuff, of a particular nutrient or, indeed, of a fuel, is expressed as the amount of heat which it produces when it is burnt completely, the carbon and hydrogen it contains being completely oxidized to carbon dioxide and water, and the nitrogen liberated as free nitrogen gas. The estimation is made in an apparatus known as a bomb calorimeter. A known amount of the material is placed in a steel bomb in an atmosphere of pure oxygen, and the bomb is placed in a known volume of water. The bomb is then fired electrically, the material burns, and the rise in temperature of the water is noted. The amount of heat given out can then be calculated. When pure fat is burned its calorific value is found to be 4·2 therms per lb. Pure starch gives a value of 1·86 therms, linseed cake 2·1 therms, and hays, straws, and cereal meals about 1·8 therms per lb. Anthracite coal gives a value of about 3·6 therms per lb. It is obvious that these figures do not give very much indication of the value of the food to the animal, otherwise we would conclude that anthracite coal was a better feed than linseed cake, and that barley meal was about equal in feeding value to wheat straw. Gross energy values only state what energy the food contains ; they give no information at all on the amount which the animal can obtain from it.

In the first place, only such portions of the food which can be digested by the animal furnish it with any useful energy. Those portions which appear in the fæces have not been digested. Furthermore, some substances are excreted by the body before they have been completely oxidized. Thus the nitrogen contained in the digestible protein of the food is not excreted as gaseous nitrogen, but is locked up in compounds such as urea, hippuric acid, and ammonia. These substances are incompletely oxidized and their excretion means a loss of energy to the animal. Again, the fermentations which take place in the rumen of the ox or sheep entail the production of combustible gases, mainly methane or marsh gas, and, under some conditions, hydrogen. This again represents a loss of energy to the animal. To obtain a measure of the useful energy which an animal obtains from its food it is necessary to deduct from the gross energy which it ingests the energy lost in the fæces, the urine, and as combustible gas. The balance is called *metabolizable energy*, a term which is better than "useful" energy since, as will be explained later, not all of it can be used by the animal for meeting its requirements for maintenance or production.

Professor Armsby, an American who was one of the first to study the energy metabolism of farm animals, gave the following example of the calculation of the metabolizable energy of a steer's ration. The steer was given a ration of timothy hay and its liquid, solid, and gaseous excreta were collected. The total energy values of food and its excreta were then determined :—

	Calorific Value (therms)
Energy of food—	
6,988 gm. timothy hay	27·72
400 ,, linseed meal	1·81
Total intake	29·53
Energy of excreta—	
16,619 gm. fæces	14·23
4,357 ,, urine	1·21
142 ,, methane	1·90
Total excreted	17·34
Difference, being the metabolizable energy of the ration	12·19

Not all the metabolizable energy, however, can be used by the animal for productive processes or for meeting its maintenance

requirement. A portion is always lost as sensible heat. This is not surprising since, to take an example in the manufacture of milk by the cow, it is clear that a great deal of internal work has to be done. The cow must spend part of the metabolizable energy in the work of prehension, mastication, digestion, and assimilation of her food, and a further part in the transference of absorbed nutrients to her udder. Even there, the efficiency of the biochemical transformations involved in the making of milk is never a hundred per cent., so that there is a further wastage of dietary energy. The energy expended in the work of digestion and the losses entailed in metabolic transformations of metabolizable energy is eventually given up as heat. This heat may be of value, under certain conditions, for keeping the animal warm, but in general it is a waste product, and, indeed, in very hot weather, is a liability.

For each animal receiving a particular ration there is what is called a critical temperature. This represents the air temperature at which the animal's normal body processes generate just sufficient heat to maintain its body temperature at the normal level. If the air temperature drops below this critical temperature, the animal has to expend energy in movement, such as shivering, in order to keep its body temperature at the normal level. When chicks huddle together or pigs crawl under their litter, it may be assumed that the air temperature has dropped below their critical temperature for the prevailing conditions of feeding, humidity, etc. With the adult pig on full feed the critical temperature is about 40° F.; only if the temperature falls below this level will food energy be diverted from the useful path of laying down fat and protein in the body and be squandered by the animal in order merely to keep itself warm. Young pigs and baby chicks have much higher critical temperatures than adult pigs and hens, and thus it is important, when the weather is cold, to provide them with additional heat. Ruminants, on the other hand, when given normal rations, have very low critical temperatures. Cowshed temperatures below freezing-point have no effect on the utilization of feed by cows. This is largely to be explained by the fact that the extensive fermentations which take place in the paunch produce a considerable amount of heat; thus, while a pig derives about 1500 kilogram Calories from 1 lb. of barley meal, a cow or sheep loses, as heat, about 500 extra kilogram Calories. It is thus a mistake to suppose that feed can always

be saved by keeping animals warm. This will happen only if the temperature of the surroundings drops to below the critical temperature, and is likely to occur only with pigs or poultry when poorly housed. It is true that, in severe winters, deaths of hill sheep do occur, but the deaths are largely due to the combination of starvation and cold; as the animals get less and less to eat, and thus have less and less waste heat available, the critical temperature rises. A fasting animal has a critical temperature which may be as much as 50° F. above that of one on a normal diet. Thus, the critical temperature of the hill ewe rises, her reserves of energy in the form of body fat are exhausted, and eventually she can no longer equate her heat production with heat losses, when the body temperature falls and she dies.

At the other end of the scale high air temperatures impose a considerable strain on the animals' means for getting rid of heat. At high environmental temperatures, cattle and sheep, which have no well-developed sweating mechanism, have to rely on the evaporation of water from their respiratory passages to keep themselves cool, and pant vigorously. As air temperature rises further the animal is unable to get rid of enough heat and the body temperature rises. This rise appears to result in the acceleration of many of the body processes, and the animal's expenditure of energy thus increases. The temperature at which this takes place is called the *point of hypothermal rise*, and between this and the critical is what is called the *range of thermal neutrality*. Within this range the animal's expenditure of energy is not affected by variation of air temperature. Just as a lowered food intake increases the critical temperature so, at the other end of the scale, a lowered intake raises the point of hypothermal rise. In other words, an animal on a low level of nutrition has a relatively high heat tolerance. This is of considerable importance in tropical countries, since it means that, under the hot, humid conditions, high levels of feeding cannot be used. Dairy cows imported from temperate regions deteriorate under these hot conditions and give little milk because they cannot maintain the food intake necessary for high milk yield and yet keep their body temperature normal. The tropical breeds of cattle are better equipped to get rid of surplus heat than are those of temperate regions.

If from the metabolizable energy we deduct the amount of energy lost in the form of heat as a result of (1) fermentation

in the alimentary tract, (2) the work of digestion, and (3) the inefficiency of metabolic transferences within the body, we obtain a balance which is known as *net energy*. The net energy per pound of food ingested is known as the *net energy value* of the food concerned. It represents the energy of the feed which the animal actually uses for maintenance of its vital processes or deposits as fat or protein in its body or secretes in its milk. The maintenance cost, in terms of net energy, is, however, a first charge on the total supply. Only the surplus is available for tissue growth, fat deposition, or the production of milk or eggs.

The net energy values of some feeding stuffs and some pure nutrients are given in the following table:—

Energy Values in Therms per Lb. as determined with Fattening Cattle

Food	Gross Energy	Energy lost in			Metabolizable Energy	Energy Lost as Heat	Net Energy Value
		Fæces	Urine	Methane			
Earth-nut oil	3·99	0·00	0·00	0·00	3·99	1·74	2·25
Wheat gluten	2·63	0·00	0·49	0·00	2·14	1·18	0·96
Starch	1·86	0·00	0·00	0·19	1·67	0·69	0·98*
Maize meal	1·80	0·21	0·08	0·16	1·35	0·52	0·83
Timothy hay	1·81	0·86	0·07	0·14	0·74	0·31	0·43
Wheat straw	1·85	1·08	0·04	0·15	0·58	0·47	0·11

* In more extensive experiments, Kellner found the average net energy value of starch to be 1·071 therms per lb.

It is clear from the table that the proportion of the gross energy which is metabolizable, and also the proportion of the metabolizable energy which is really of value to the animal as net energy, varies considerably from one feeding stuff to another. Although the gross energy value of wheat straw is slightly higher than that of maize, the fattening steer obtains only about one-eighth as much net energy from straw as from maize.

The net energy values of feeding stuffs are not, however, the same for all animals. This was first shown by Oskar Kellner, a famous German nutritionist, who devised the system still used in Britain for the rationing of live stock, and which has since been extended by other workers. Kellner found that when he added 1 lb. of starch to the maintenance ration of a steer, the steer stored 0·25 lb. of body fat each day. Since the energy value of fat is about 4·28 therms per lb., the net energy value of starch

for the steer was 1·07 therms per lb. When the same experiment was made with the pig, however, it was found that the net energy value was 1·50 therms per lb. The pig is therefore a much more efficient animal than the steer in utilizing the energy of materials such as starch. This difference in efficiency reflects the differences between the digestive process of the two species. The pig has a simple digestive system well adapted to the utilization of concentrated foods, while the digestive process of cattle involves a massive bacterial fermentation of feeds prior to their digestion lower down the alimentary canal. This bacterial fermentation, though well adapted to make the greatest use of coarse fibrous foods, necessarily wastes a good deal of the energy of easily digestible materials such as starch. The difference in efficiency in the utilization of starch by the pig and steer does not mean the pig is, in general, superior as a food converter. The opposite conclusion would have been reached if a feed containing 12 to 15 per cent. of crude fibre had been used in the experiment.

Since the net energy value of a feed is the difference between the metabolizable energy it supplies and the expenditure of energy involved in its assimilation, it will be clear that, if the expenditure of energy exceeds the supply, the net energy will be a negative quantity. Such values have been found with sawdust and peat moss. Wheat straw has very little value for ruminants, and for horses is worse than useless, since the horse expends far more energy in eating and digesting it than the straw yields in metabolizable form.

The basis of live-stock rationing in Britain is the net energy system outlined above, but energy values are expressed in other units, viz., in terms of a reference substance, starch, rather than as kilogram Calories. The *starch equivalent* of a feeding stuff thus represents the number of pounds of pure starch which would have to be fed to an animal to give the same practical result, in terms of fat deposition, as 100 lb. of the feeding stuff. The starch equivalent system was devised by Kellner, and is essentially the basis of most Continental systems of rationing, such as the feed-unit systems of Scandinavian countries.

The determination of the starch equivalents of feeding stuffs is an extremely difficult task. Kellner determined them by experiments with fattening steers in an apparatus which enabled him to measure the storage, by a steer, of both carbon and nitrogen. This was done by confining the steer in a respiration chamber,

measuring the carbon lost in dung and urine, and calculating the carbon-content of the carbon dioxide lost in respiration and also in the methane produced by fermentation. From the results Kellner calculated the amount of fat stored by the steer when a particular feed was given as an addition to a maintenance ration. He thus found that the addition to the maintenance ration of 10 lb. of linseed cake resulted in the formation of as much fat as was produced from 7·4 lb. of starch. Hence, expressed per 100 lb., the starch equivalent of linseed cake is 74. In the early years of the present century Kellner worked out many starch equivalents, but later realized that a more simple method of determination was needed. He therefore devised a method for calculating the starch equivalent of a feeding stuff from its content of digestible nutrients, *i.e.* from the amount of digestible protein, digestible ether extract, and digestible carbohydrates it contained. The energy value of the above nutrients were found to be as follows:—

1. Each pound of digested crude protein supplies as much energy as 0·94 lb. of starch.
2. Each pound of digested carbohydrates supplies the same amount of energy as 1 lb. of starch.
3. Each pound of digested ether extract supplies as much energy as 1·91, 2·12, or 2·41 lb. of starch, the different values being allotted to allow for the varying composition of the ether extract of different feeds. The highest factor applies to oil seeds containing much true fat, and the lowest to hays and straws in which the ether extract is mainly pigments and resins. The intermediate figure applies to cereals.

When Kellner applied these factors to the digested nutrients of feeding stuffs and compared the calculated starch equivalent with his experimental observations made in the respiration chamber, he found that the results failed to agree. The calculated figure was always greater than that actually determined by calorimetry. The difference was greatest in the case of fibrous foods—hay, straw, and other coarse fodders—when the calculated figures were often as much as 40 per cent. too high. Obviously the work of prehension and mastication of the fodder and of the propulsion of indigestible matter along the tract had not been taken into account in his calculations. Kellner therefore devised

two sets of correction factors. One he called "V factors," to be applied to meals and grains. These are simple percentage values indicating the discrepancy between calculated and observed results. Thus a V factor of 97 for linseed cake means that the true starch equivalent of linseed cake is only 97 per cent. of the calculated value. The other corrections for roughages he based on a sliding scale to take into account the fibre-content, making a deduction from the calculated figure for each 1 per cent. of fibre in the material. For fresh green fodder the factor used was 0·29, and for the mature hays and straws 0·58. The following example shows how the starch equivalent of a sample of ryegrass hay may be arrived at:—

Digestible protein, 4·9 per cent. × 0·94	= 4·61
,, fibre and nitrogen-free extract, 41·5 per cent. × 1·00	= 41·50
,, ether extract, 1·4 per cent. × 1·91	= 2·67
	48·78
Correction—	
Fibre-content = 22·9 per cent. × 0·58	= 13·28
Starch equivalent per 100 lb. .	35·50

Tables in the Appendix give the starch equivalent, protein equivalent, and average content of digestible nutrients of most of the common feeding stuffs of the farm.

Most of the starch equivalents used in Britain for live-stock feeding have been calculated in this manner; indeed, no single direct determination has been made with cattle. It must be remembered that the foods used by Kellner in Germany fifty years ago may have been rather widely different from those in Britain to-day. We have new crop varieties, and some new crops such as sugar and fodder beets, new farm processes such as grass-drying and modern ensilage. Again, the factory by-products now available for feeding have been more highly processed than those of fifty years ago. It is thus not surprising that many writers have criticized the starch-equivalent system, often because they have expected the calculated figures to be more precise than, in fact, they pretend to be. Calculated values are not precise, but the results of practical feeding trials do conform fairly closely to expectations based on the book values.

The starch equivalents calculated in the manner given above estimate the values of feeding stuffs to ruminants. As already

pointed out, pigs and poultry will make better use than ruminants of some feeds. Armsby, for instance, found the net energy value of maize for fattening cattle to be 85 therms per 100 lb. and for the pig 120 therms. It would, of course, be useful to have a separate set of starch equivalents for pigs and poultry, but in general it has been found that the *relative* values of feeding stuffs are approximately the same for different classes of stock. Thus experiments with pigs show the starch equivalent of potatoes to be 20 per cent. of that of maize, while experiments with cattle show potatoes to have 23 per cent. of the value of maize. Obviously hay and straw, which ruminants can and pigs and poultry cannot use, could not be expected to conform to this generalization, but, for all but fibrous foods, starch equivalents determined with cattle can be used in the computing of rations for other classes of farm stock.

Food Requirements.—It is quite clear that starch equivalents are *estimates* of the amount of energy that animals obtain from particular feeding stuffs. The energy requirements of particular animals are estimates also and can be expected to apply only to the average individual. Two animals may be exactly the same size, yet one may require more food than the other to maintain itself and make a given amount of growth or lay on a given amount of fat. This is understandable, for one may be a placid individual taking very little exercise and the other a highly strung creature dissipating much more energy in body movement or nervous tension. It must be emphasized that a system of rationing according to theoretical requirements is no more than an aid to good stockmanship. Precise rationing of animals according to feeding tables will, on average, give good results; but the knowledgeable stockman realizes the inevitable margin of error and makes minor adjustments in the ration of individual animals. Rationing, if done intelligently, prevents waste of food. For example, it was common farm practice, fifty years ago, to feed fattening bullocks enormous quantities of high-protein cakes. Much of this protein was surplus to the animals' needs, and the nitrogen it contained was simply excreted in the urine. Knowledge of energy and protein requirements and values has enabled this waste to be avoided.

In rationing farm stock the primary object is so to adjust the energy and protein supply to enable the animal to realize something near its potential level of production and to avoid waste.

As said previously, mineral and vitamin requirements must also be provided for.

Energy Requirements for Maintenance.—The maintenance energy requirement of an animal is made up of two parts: the basal or minimal metabolism and the activity allowance. Basal metabolism measures the heat lost by an animal when it receives no food at all and is lying in a state of complete rest. Very few determinations of it have been made with farm animals. Muscular activity increases the animal's energy loss—even standing without movement increases heat production by 15 per cent. while short bursts of activity such as galloping or struggling increase it as much as threefold or fourfold. In stall-fed cattle provision for basal metabolism normally accounts for about 70 per cent. of the total maintenance cost. It has been found by controlled experiments, and confirmed by feeding trials, that the average maintenance requirement (including both the basal allowance and that for activity) of a 1000-lb. ox under conditions of close confinement is 6 lb. starch equivalent per day. This value is only an average, and individual oxen weighing 1000 lb. may have maintenance requirements as much as 25 per cent. more or less. Obviously, on average, animals heavier than 1000 lb. will require more and lighter animals less. It has been shown by a careful study of the records made with many species that basal metabolism varies not directly with body weight but with body weight raised to the power 0·73. The live weight to the power of 0·73 is called "metabolic body size." It is a mathematical expression of the general finding that basal metabolism is roughly proportional to the animal's surface area, *i.e.* the area from which it radiates heat. This generalization applies, however, to mature animals only and to basal metabolism only. It does not permit any reliable estimates to be made, by simple arithmetic, of the maintenance requirements of very young animals. Young growing animals tend to have much higher maintenance requirements than would be estimated from their "metabolic body size." Thus the maintenance energy requirement of a mature sheep weighing 100 lb. is approximately 1200 kilogram Calories per day, or 1·1 lb. starch equivalent per day, whereas a young calf of the same weight has a maintenance requirement of 1950 kilogram Calories. A young calf only one-tenth the weight of an adult cow has a maintenance energy requirement of about one-third that of the adult. With adult

animals, however, it is fairly safe to use the metabolic body size in computing requirements. Even here, however, it appears that Jersey cows require more maintenance energy in proportion to their metabolic size than those of larger breeds. Indeed, it seems necessary to use slightly more liberal allowances for milking cattle than for others.

Maintenance Requirements of Growing and Fattening Cattle

Live Weight (lb.)	Maintenance Energy Requirement (lb. Starch Equivalent per Day)	Maintenance Protein Requirement (lb. Protein Equivalent per Day)
300	2·8	0·25
400	3·3	0·32
500	3·8	0·36
600	4·2	0·42
700	4·7	0·47
800	5·1	0·51
900	5·5	0·55
1000	6·0	0·60
1100	6·5	0·65
1200	6·9	0·69
1300	7·3	0·73
1400	7·7	0·77
1500	8·1	0·81
1600	8·5	0·85

Manitenance Requirements of Adult Milking Cows of Average Size

Breed	Maintenance Energy Requirement (lb. Starch Equivalent per Day)	Maintenance Protein Requirement (lb. Protein Equivalent per Day)
Jerseys . .	5·5	0·51
Guernseys .	6·3	0·55
Ayrshires .	6·5	0·60
Shorthorns .	7·4	0·70
Friesians .	7·6	0·70

With sheep there are very few estimates of maintenance requirements, but recent experiments suggest that the older results are approximately correct. As with cattle, there are undoubtedly breed differences in maintenance requirement. Hill ewes doubtless expend more energy than a folded flock in searching

for their food. The following table gives estimates of requirements for the maintenance of sheep :—

Live Weight (lb.)	Maintenance Energy Requirement (lb. Starch Equivalent per Day)	Maintenance Protein Requirement (lb. Protein Equivalent per Day)
60	0·73	0·08
80	0·90	0·10
100	1·07	0·12
120	1·23	0·14
140	1·38	0·16
160	1·52	0·17
200	1·79	0·20

Under present-day conditions in Britain these figures are of no more than academic interest since the accurate rationing of energy for sheep, even on a group basis, is impracticable. In moving sheep from one pasture field to another, or in setting off an area of forage crop for, say, a week's consumption, or again in deciding whether or how much supplementary food should be offered, the farmer or the shepherd must be guided by experience, and by the appetite, bodily condition, and general behaviour of the sheep. It is only where sheep are housed in winter, or fed in "dry lot," that any system of rationing can be applied.

With pigs there have been many experiments, notably at Cambridge, in Denmark, and in Germany, in which maintenance requirements have been determined in calorimeters and respiration chambers. Their practical value is not very great since most pigs grow too rapidly to allow adjustment of their rations on the basis of calculated maintenance requirements. The all-meal system aims to provide the pig with a ration containing about 70 lb. starch equivalent per 100 lb. of dry matter, and the daily allowance of meal is periodically adjusted to appetite. In the later stages of fattening for bacon some restriction of feed is often necessary to the production of good carcass quality, without excessive fat. With the Lehmann feeding system, the rationing is based on a restricted ration of meal containing sufficient protein and minerals to "balance" a bulky supplement of potatoes, fodder beet, kitchen waste, etc., which is fed to appetite.

With farm horses the basal metabolism is roughly the same as for cattle of equivalent weight, and the requirement for normal activity,

when the horse is not working, is also about the same. The horse tends to make slightly better use of its feed, for maintenance, than does the ox, largely because fermentative losses are not so great.

Protein Requirements for Maintenance.—The requirement of animals for protein is largely accounted for by their need for amino-acids to manufacture the proteins of new tissues or of milk. But animals that are neither growing nor producing milk need protein to replace the nitrogen-containing constituents of the tissues, which are constantly being broken down. An animal on a protein-free ration must thus lose nitrogen from its body. On such a ration nitrogen is found in the fæces, partly in the residues of digestive juices, and partly in the millions of cells that are abraded day by day from the walls of the digestive tract. Similarly, losses occur in the form of scurf and hair. The nitrogen in the urine represents the inevitable loss of cell constituents incidental to the normal metabolic processes of the body cells. Maintenance requirements of protein are measured by feeding animals protein-free or protein-low rations and measuring the total losses of nitrogen from the body. The figure so obtained represents the minimal requirement of the animal which, for an adult steer weighing 1000 lb., amounts to about 0·20 lb. protein per day. But the amount of food protein required to achieve balance is considerably higher, viz. 0·5 to 0·6 lb. of protein equivalent per day. As in the case of basal energy requirements, protein requirements for maintenance are proportionate to the metabolic body size and not directly to the body weight. By contrast with the maintenance energy requirement, however, muscular activity has no effect on maintenance protein requirements provided that sufficient energy is provided in the form of carbohydrate, fat, etc. The tables on pages 573 and 574 give the maintenance requirements in terms of protein equivalent of cattle, horses, and sheep. Obviously the production of wool by the sheep—containing about some 2 or 3 oz. of pure protein per week—necessitates an additional requirement. Allowance is made in the tables for this extra demand.

Production Requirements.—(1) *Energy.*—By definition, 1000 kilogram Calories of net energy (0·94 lb. starch equivalent) fed to a fattening ox will result in the deposition of 1000 kilogram Calories in the form of fat. This is equivalent to about 4 oz. of pure fatty tissue. The production of 1 lb. of fat in a mature steer thus requires nearly 4 lb. starch equivalent. Fat is not only

stored in fat "deposits," *e.g.* the subcutaneous layer and the "caul," but also in the muscles, and without any concomitant storage of water. Hence the deposition of 1 lb. of fat means also 1 lb. of live-weight increase. But in animals that are both growing and fattening it is only in the last stages of fattening that 1 lb. of live-weight gain represents the gain of 1 lb. of fat. In growing animals part of the energy of the food that is surplus to maintenance is used in the building up of body tissues. Moreover, when protein is laid down in muscles and other tissues it is accompanied by about four times its weight of water. Thus we find that, in young calves, the live-weight gain contains only some 10 to 15 per cent. of fat, the remainder being distributed between ash (about 10 per cent.) and protein (15 per cent.), with as much as 65 per cent. of water. The energy value of 1 lb. of live-weight gain thus varies widely—between about 800 kilogram Calories in animals growing and laying down muscle and bone, and 4000 kilogram Calories in fully grown fattening animals. Indeed, the energy value of 1 lb. of gain may be actually higher than the value of 4000 kilogram Calories since, in the last stages of fattening, added fat may replace body protein or body water. Hence the amount of starch equivalent required to produce 1 lb. of live-weight gain will vary from less than 1 lb. to fully 4 lb. A rough estimate of the requirement per pound of live-weight gain can be based on the age of the animal and the rate of live-weight gain. Thus a young calf, growing but not fattening, has the lowest requirement. An older animal, being maintained in store condition, will need rather more. A fattening beast requires more in the later than in the early stages of fattening. In the tables below account is taken of all these variables.

Requirements of Ruminants for Growth and Fattening

Normal growth without fattening (growing dairy stock and lambs destined for breeding) -

Cattle		Sheep	
Age (months)	Lb. S.E. per Lb. Live-weight Gain	Age (months)	Lb. S.E. per Lb. Live-weight Gain
0 to 3	1¼	0 to 3	1¼
3 ,, 6	1½	3 ,, 6	1¾
6 ,, 12	2	6 ,, 12	2¼
12 ,, 24	2¼		

Fattening of young cattle and sheep (baby beeves, fattening lambs, and young fattening tegs)—

Early stages of fattening .	2 lb. S.E. per lb. live-weight gain.
Later ,, ,, .	3 ,, ,, ,,

Fattening of older cattle and sheep (cattle of 2½ years or over, including old cows; sheep over 9 months, including old ewes)—

Early stages . . .	2½ lb. S.E. per lb. live weight.
Middle ,, . . .	3 ,, ,, ,,
Late ,, . .	3½ to 4 ,, ,, ,,

With pigs the same general principles apply but, as mentioned earlier, it is usual to express requirements in terms of total 'meal " per day. Requirements are discussed in Chapter VI.

Again, in the case of milk it will be obvious that account must be taken of the variable composition of the product: for example, more food energy will be needed to produce a milk containing 5 per cent. of fat than one containing only 3 per cent. A gallon of milk with 4 per cent. of fat has a calorific value of 3400 kilogram Calories, which would suggest a requirement of about 3 lb. starch equivalent. In fact, the need is less because the conversion of energy into milk is more efficient than conversion into live-weight gain. The usual recommendation is 2·5 lb. starch equivalent for each gallon of average milk containing 3·75 per cent. fat. But practical experience and also experimental evidence indicate that somewhat higher amounts lead to better sustained yields. The amounts of starch equivalent given below are 0·2 lb. higher than those usually recommended, and quoted on page 632.

Energy and Protein Requirements for Milk Production

Fat-content of Milk (per cent.)	Lb. Starch Equivalent (per gallon)	Lb. Protein Equivalent (per gallon)
3·00 to 3·50 . .	2·4	0·48
3·50 ,, 4·00 . .	2·7	0·55
4·00 ,, 4·50 . .	3·0	0·62
4·50 ,, 5·00 . .	3·2	0·69
5·00 ,, 5·50 . .	3·5	0·76
5·50 ,, 6·00 . .	3·7	0·83

Even so, higher intakes of starch equivalent than the standards above suggested will result in higher milk production. Much recent experimental work has shown that high planes of nutrition,

entailing feeding at levels above those given by feeding standards, will result in substantial increases in milk yield and, incidentally, in body weight. Many of the high average yields of individual dairy herds may be traced to the very high levels of feeding which are employed. High levels of feeding may not, indeed, always be profitable. In general, however, it should be remembered that levels of feeding above the accepted standards are bound to give some increase in milk yield since the law of diminishing returns applies to milk production; but experience has shown that it may take nine months, or perhaps longer, before the effects of a large increase in the feeding level are reflected in an overall economic gain of milk.

For work production there are no reliable figures, and the following are rough guides to feeding working horses:—

Requirements for Working Horses

	Starch Equivalent Required per Working Hour (per 1000 lb. body weight)
Light slow work . . .	$\frac{3}{4}$
Medium slow work . . .	1
Heavy slow work . . .	$1\frac{1}{4}$
,, fast work . . .	$1\frac{1}{2}$

(2) *Protein.*—The amount of protein required for productive purposes is determined by much the same factors that apply in the case of energy. If the live-weight gain is largely protein, as it is in the case of a young and rapidly growing calf, then relatively more protein will be needed than in that of an adult fattening beast, which is storing up little except fat. As the young animal grows, it, of course, has a rising maintenance requirement, but proportionately less for the build-up of tissue. These two opposites almost cancel out, so that, for instance in the case of cattle, a constant daily allowance of 0·9 lb. protein equivalent per head will cover the daily requirement from an age of about five or six months (3 cwt. live weight) to maturity. A constant allowance of 0·9 lb. protein equivalent over this weight range, having regard to rising energy needs, thus implies a widening of the nutritive ratio of the ration as the animal gets older. The nutritive ratio may be expressed as that between protein equivalent and the starch equivalent in the ration as a whole. The same figure applies to fattening cattle, good results having been obtained on a daily allowance of 0·9 lb. In practice,

however, more than this amount of protein is ordinarily given, because rations with very wide nutritive ratios are rather unpalatable. The figure of 0·9 lb. should thus be regarded as a minimum. A higher allowance will do no harm, and although it may increase the cost of the ration it will often be necessary to maintain the desired level of food consumption. An allowance of less than 0·9 lb. may retard growth.

With sheep and lambs the same general principles apply, and a constant allowance of 0·20 lb. protein equivalent per head per day will suffice for maintenance, growth, and fattening in lambs and tegs of ordinary size.

Turning to the dairy cow, it has been shown that milk of high fat-content also has a high protein-content. Hence the protein allowance, per gallon, must vary with the fat-content of the milk. In the past it has been customary to feed 0·6 lb. protein equivalent per gallon of average composition; but extensive feeding trials have shown that this figure can be reduced to 0·5 lb. without causing any significant fall in yield. These results may indeed reflect the "margin of safety" in the maintenance part of the ration; and despite the experimental evidence for the level of 0·5 lb. it may be better, in practice, to adopt a standard of 0·55 lb. per gal. Protein requirements for milk production are set out in the table on page 632.

Appetite.—There is a fairly definite limit to the amount of food that an animal can eat in a day or at a meal. On the other hand, there is a minimum required to satisfy the appetite. Too bulky a ration will simply be refused, while a too concentrated one, besides not being sufficient to satisfy the animal's hunger, may result in digestive disturbances. The bulk of a ration is usually measured by its dry-matter content, but this measure is not entirely satisfactory. Animals will, in general, eat more of high-quality foods than of low-quality fibrous ones. It is probable that "space-filling" is better measured by the content of indigestible residues, or "ballast," than by dry-matter content. The former measure is used on the Continent, but it is not the ideal one. In this country we commonly express appetite, and the need for bulk, in terms of dry matter, recognizing, however, the limitations of this measure. For cattle and horses the lower limit is about 15 lb. dry matter per 1000 lb. live weight daily, while normal rations may, in general, contain up to 25 lb. Dairy cows tend to have larger appetites than other classes of cattle; in fact,

some very heavy milkers can consume as much as 40 lb. dry matter daily if the total amount is divided into four or five meals. Lean store stock can also deal with slightly more than the usual 3 lb. of dry matter per cwt. of live weight, which is the commonly accepted figure in their case. For sheep 2½ to 3 lb. dry matter per 100 lb. live weight per day is a normal intake. With pigs a good rule is to arrange for the starch equivalent of the ration to be three-quarters of the dry-matter content. Pigs will eat about 4½ lb. dry matter per day per 100 lb. body weight when weaned at two months old, decreasing to about 3 lb. as they reach bacon weight.

In general, appetite is expressed per 100 lb. of live weight. But the figures quoted above do not apply to the young calf or to other animals at the suckling stage. These must have a diet of high energy value in relation to its bulk, *i.e.* composed largely of concentrated and easily digested materials, if full growth is to be secured.

There are many other factors which must be taken into account in the practical rationing of animals. The palatability of foods is one which is often ignored but is of considerable importance. When strange foods are introduced they generally prove unpalatable to at least some individuals. Certain breeds, such as Jerseys, tend to be more than ordinarily fastidious. The effect of the feed on the health of the animal is another matter. Unsterilized bone flour might possibly introduce anthrax spores and cause disease, while there is much farming experience to suggest that some feeds are conducive to fertility or, conversely, result in poor reproductive performance. The latter opinion, however, has not been sufficiently examined experimentally. Some foods, such as rice meal and maize, result in the production of too soft a fat in bacon pigs, while others produce a milk fat that is too hard or too soft for butter-making. Other feeds, such as turnips and molassed sugar-beet pulp, may cause taints in milk. Again, some feeds, such as cotton cake, have a costive action and thus may find a use at particular times when the major part of the ration is too laxative. Conversely, linseed cake is laxative.

Hence, in drawing up rations, it is not enough to adjust the starch equivalent and protein equivalent to the calculated requirements. Individual animals do not conform closely to general rules.

The following examples illustrate the application of the principles set out above.

1. *Daily Winter Ration of a Rapidly Growing Dairy Heifer Twelve Months Old weighing* 500 *Lb.*—The appetite of this animal will be about 14·5 lb. dry matter. For maintenance it will require 3·8 lb. starch equivalent. Normal growth will be about 1½ lb. daily, implying a further 3 lb. starch equivalent and giving a total of 6·8 lb. Protein requirements will be 0·9 lb. If mangolds, hay, and dredge corn (equal parts oats and beans) are available, the calculation would be:—

Energy supply—	Lb. S.E.
20 lb. mangolds (starch equivalent = 6·2)	= 1·24
12 ,, good hay (starch equivalent = 37)	= 4·44
1 ,, oats (starch equivalent = 60)	= 0·60
1 ,, beans (starch equivalent = 66)	= 0·66
Total .	6·94

Protein supply—	Lb. P.E.
20 lb. mangolds (protein equivalent = 0·4)	= 0·08
12 ,, hay (protein equivalent = 4·7)	= 0·56
1 ,, oats (protein equivalent = 7·6)	= 0·08
1 ,, beans (protein equivalent = 19·7)	= 0·20
	0·92

The total dry weight of the ration can be calculated to be 14½ lb. daily. The above ration could then be fed for a period and later be adjusted according to the results secured.

2. *Ration for a Friesian Cow giving* 4 *Gals. of Milk containing* 3·75 *per cent. Fat.*—The requirements of the cow would be:—

	Starch Equivalent (lb. per day)	Protein Equivalent (lb. per day)
Maintenance for 1250 lb. live weight	7·6	0·70
Production (2·7 lb. starch equivalent and 0·55 lb. protein equivalent per gallon)	10·8	2·20
Total .	18·4	2·90

The appetite of this cow will probably be about 3 lb. of dry matter per cwt., *i.e.* 33 lb. daily. Under present-day conditions it is commonly advisable to feed bulky home-grown foods for part

of the production ration as well as the maintenance ration. A suitable ration would be :—

	Lb. S.E.
Energy supply—	
20 lb. marrow-stem kale (starch equivalent 9) . .	=1·80
20 ,, arable silage (starch equivalent 12) . . .	=2·40
15 ,, good meadow hay (starch equivalent 37) . .	=5·55
6 ,, crushed oats (starch equivalent 60) . . .	=3·60
4 ,, cracked beans (starch equivalent 66) . .	=2·64
2 ,, dried sugar-beet pulp (starch equivalent 61) .	=1·22
½ ,, decorticated ground-nut meal (starch equivalent 73)	=0·36
1 ,, flaked maize (starch equivalent 84) . . .	=0·84
	18·41

	Lb. P.E.
Protein supply—	
20 lb. marrow-stem kale (protein equivalent 1·3) . .	=0·26
20 ,, arable silage (protein equivalent 2·0) . .	=0·40
15 ,, good meadow hay (protein equivalent 4·6) . .	=0·69
6 ,, crushed oats (protein equivalent 7·6) . . .	=0·45
4 ,, cracked beans (protein equivalent 19·7) . .	=0·79
2 ,, dried sugar-beet pulp (protein equivalent 5) .	=0·10
½ ,, decorticated ground-nut meal (protein equivalent 41)	=0·20
1 ,, flaked maize (protein equivalent 9) . . .	=0·09
	2.98

In practice the purchased sugar-beet pulp, decorticated ground-nut meal (or cake), and flaked maize would be mixed with the home-grown oats and beans, 2 per cent. of a mineral mixture added, and the whole fed at the rate of 4 lb. per gal. for milk produced above the first gallon daily. The ration of marrow-stem kale, silage, and hay would be sufficient for cows producing one gallon only. The physical condition of the concentrate mixture might be rather fluffy, a difficulty that could be overcome by adding some heavier material such as maize gluten feed or palm kernel cake; both of these are approximately balanced for milk production.

CHAPTER III

CATTLE—TYPES AND BREEDS

THE term cattle, originally used to include all classes of live stock, is now generally restricted to oxen, which are included by zoologists in the genus *Bos*. This genus comprises the wild and domesticated buffaloes of Asia, and some two or three wild African species of buffalo; the American and the European Bison; the Yak of Tibet; three species of Asiatic cattle—the Gaur, Gayal, and Banteng—all of which are found wild, while the last two are also kept under domestication; the domesticated humped cattle (Zebus) of Asia and Africa; and lastly our European domesticated types. The buffaloes do not cross with the others in the list, but these others cross freely, and the hybrids (or at least the female hybrids) are fertile.

Domesticated cattle are known to have existed in Babylon as early as 5000 B.C. The earliest known domesticated type found in Europe is that known as *Bos taurus brachyceros* or *Bos longifrons*, a very small, slightly built ox with short horns, which was very widespread in the earliest Neolithic (polished stone) period. There is no evidence that it was evolved in Europe, and the accepted view is that it was introduced from Asia as an already long-domesticated animal. This type, sometimes known as the "Celtic Shorthorn," persisted in Britain till Roman times, but on the Continent it was displaced much earlier by a large, strong-boned, and long-horned animal known as *Bos taurus primigenius*. This seems to have been produced either by crossing the older form with the native wild species, or perhaps by direct domestication of the latter, the old type being meanwhile discarded. The European wild Ox or Urus (*Bos primigenius*) was common in Europe during the Roman period, and the last known specimen was killed in Poland in 1627. It was a very large and powerfully built animal with long horns, and probably brown in colour.

European cattle comprise a great variety of types. Quasi-zoological classifications of these types have been proposed, but none is very satisfactory. As regards the British breeds, they are of very varied and frequently of mixed ancestry. Thus the native cattle before the Roman invasion were small, black or brown in

colour, with short horns (*Bos brachyceros*). The Jersey, Kerry, and Shetland probably show the largest proportion of this blood. Then, according to Professor Wilson, the Romans brought in large white animals whose descendants have been preserved as the "wild" white cattle of Cadzow, Vaynol, and Chartley, now known as Park Cattle. According to another view these park cattle are the direct descendants of the wild Urus. It is certain that the Anglo-Saxons brought over cattle which were probably red in colour and from which the Sussex and the Devon are presumably descended. Possibly the Norse invasions gave us our polled breeds, though occasional polled animals occurred before that time. Much more recently, in the seventeenth century particularly, there was a large influx of large, short-horned, and broken-coloured cattle from the Netherlands. These have had a large influence on the Shorthorn and Ayrshire, and probably a lesser influence on several other of our breeds.[1] These types of cattle have intermixed to a considerable extent, just as Celt and Saxon, Norman and Dane have intermixed to form our human population.

For practical purposes we classify cattle according to the object or objects for which they are kept, *i.e.* for labour, beef, milk, or any two, or all three. In Britain, oxen are scarcely used for work purposes, and therefore our classification is into beef, dual-purpose, and dairy types. As a matter of fact there is a gradation of types from the Jersey, which is of practically no value as a beef animal, to certain strains of Shorthorns, Herefords, and other breeds which have been selected almost entirely on beef points and which produce only enough milk to rear their calves (perhaps 200 to 300 gals.) or sometimes less. Specialisation has been carried further in Britain and America than in most other countries. On the Continent of Europe a considerable majority of breeds may be said to be dual-purpose or triple-purpose, and purely beef breeds are few and relatively unimportant.

We must endeavour to analyse as far as possible the qualities that constitute merit in a beef or in a milking animal. The breeder's ideal is, of course, not simply a high quality of meat or a large yield of milk, but beef or milk or both in such quantity and of such quality as will leave a maximum of profit to the producer. Our aim in breeding must therefore depend on the

[1] See Wilson's *Evolution of British Cattle*, Vinton, 1909.

demands of the consumer, and it is of course true that these may change from time to time. An example of such change is to be seen in the demand for small, tender joints, with a high proportion of lean meat, as compared with the popular taste of a century ago for larger joints of more mature and very much fatter meat. Nevertheless the main characteristics of a good beef or dairy animal have a permanent significance.

It follows from what has been said in Chapter II of this section that the efficiency of an animal, whether in the production of meat, of wool, of work, or of milk, depends on the ratio that obtains between the total food consumed and the quantity required for maintenance. The animal is always somewhat inefficient in the sense that it must consume a certain amount of material before it begins to produce anything at all. An animal that eats no more than a maintenance ration has obviously an efficiency of zero, and efficiency rises as production increases. Efficiency may be expressed as the energy value of the product stated as a percentage of the energy value of the food digested. On this basis a cow of medium size yielding 750 gals. per annum has an efficiency of 25 per cent. With a yield of 1100 gals. the efficiency rises to 35 per cent. Thus the more our animal eats in proportion to its maintenance ration (so long as the food is efficiently converted into the required product and the animal remains in health) the more economical does the productive process become. Hence, whether for beef or milk-production, we want a low maintenance requirement and a capacity to deal with large amounts of food. The maintenance requirement in cattle at rest has been found to be fairly uniform in proportion to the animal's size (see p. 574), but in practice the non-productive consumption does vary within rather wide limits according to the temperament of the animal and according to its opportunities for rest. The energy expenditure is substantially higher (about 15 per cent.) when the animal is standing than when it is lying down; and substantially higher again, of course, when it is walking or running. A restless animal may waste a very considerable amount of energy in useless movement. A further point is that high milk production seems to be associated with a relatively high metabolic rate, whereas a lower level of metabolism is associated with rapid fattening.

We must next briefly consider the question of *early maturity*, which is very important in the breeding of all meat-producing types. The new-born animal is short-bodied, shallow-bodied,

and long-legged. If such an animal be slaughtered and the different tissues of its body separated, it will be found that the proportion of bone and offal (heart, lungs, digestive organs, etc.) is very large, that of muscle tissue (lean meat) small, and that of fat very small indeed. As the animal grows the muscle tissue increases much more rapidly than the bone, and the general build becomes longer, deeper, wider, and more blocky. At a later stage still, if a full diet is provided, the proportion of fat rises; and when the accumulation of fat has reached the optimum (which depends on the consumer's taste) the animal is ready for slaughter. In the case of the sheep, Hammond found the proportion of bone, muscle, and fat in the leg of the new-born lamb to be 100 : 159 : 9, whereas in the mature fat sheep the ratio was 100 : 560 : 285. Now the rate at which these changes occur varies from individual to individual and from breed to breed, and so we distinguish early maturing from late maturing types. It should be understood that early maturity has nothing to do with weight for age. It is rather the capacity to "telescope" the three phases of development which follow one after the other in the late-maturing animal—*i.e.* (1) the growth of bone and offal, (2) the growth of muscle, and (3) the deposition of fat. Thus a South Devon or a Friesian steer at eighteen months old would normally outweigh an Aberdeen-Angus; but the latter would normally have a much higher proportion of fat and muscle, and a lower proportion of bone, than the others. Another important point is that while the tendency to mature early or late is an inborn characteristic, the actual achievement of early maturity depends largely on feeding. An animal of the best beef breeding, if it be kept upon a very low ration, will remain narrow, leggy, and shallow-bodied; hence there is no object in developing early maturity in strains of animals that have to live through periods of severe scarcity. Indeed an early-maturing type of animal will be permanently stunted by restriction of its food intake to a level that would suffice for the normal development of a slow-maturing type.

The object of breeding for early maturity is to achieve economy in production under favourable food conditions, because the shorter the period taken to produce a finished beast, the smaller is the proportion of the total food that is spent on maintenance. Moreover the early-maturing animal can produce meat that is fat enough while it is still tender.

The other chief aim is quality in the product—the fat animal.

This is to some extent a question of the percentage of meat in the animal as a whole. Beef is of far greater value, generally, than the other parts of the body, and hence the type of animal required is light of bone and hide and offal and thickly fleshed. Some of these characters are, however, incompatible with other desirable qualities—*e.g.* a light middle generally indicates a poor feeder. The proportion of the different cuts is also of importance. An animal with its weight concentrated in the back, sirloin, rump, and hind quarters, which are the high-priced cuts, will be much more valuable than another with a heavy neck and shoulder and a thin back. But here the differences that exist between different animals are not very large. A further point that determines the quality of the beef is the manner in which the fat is stored. Many unimproved breeds and dairy-bred animals tend to store the fat internally (for example, round the kidneys) and in a thick layer under the skin, the muscle tissues themselves remaining relatively free from fat. The result is that the carcass is wasteful, and that the lean meat, when cooked, is tough and dry. In good beef, on the other hand, much fat occurs within the muscles which, when cut across, show a characteristic "marbled" appearance, and the meat when cooked is tender, juicy, and of good flavour. This tendency to store fat abundantly within the lean meat is a most important quality in the beef animal. It is what the feeder means when he speaks of his animal "putting on flesh" during the fattening process. A minor point in connection with the quality of the meat is the colour of the fat. Most consumers object to a deep yellow colour, and some dislike a dead white. The colouring matter is largely carotene. Fat colour is in part a question of feeding and in part one of breed. The Channel Island breeds, for example, are characterized by the deep yellow colour of their body fat as well as of their milk. Mangolds and sugar-beet produce pale fats, while green foods, including green silage, give a deeper colour.

The points of a beef steer are shown in Fig. 33. The general type, which varies from breed to breed only in minor details, is a moderately long but deep and very wide block of meat on short legs. The head should be wide between the eyes and short from eye to nose; the muzzle large, the jaw strong, and the eye full and mild; the neck short, and full at its junction with the shoulder; the back wide, and almost uniform in width from crops to pin bones; the shoulder smoothly laid and well covered,

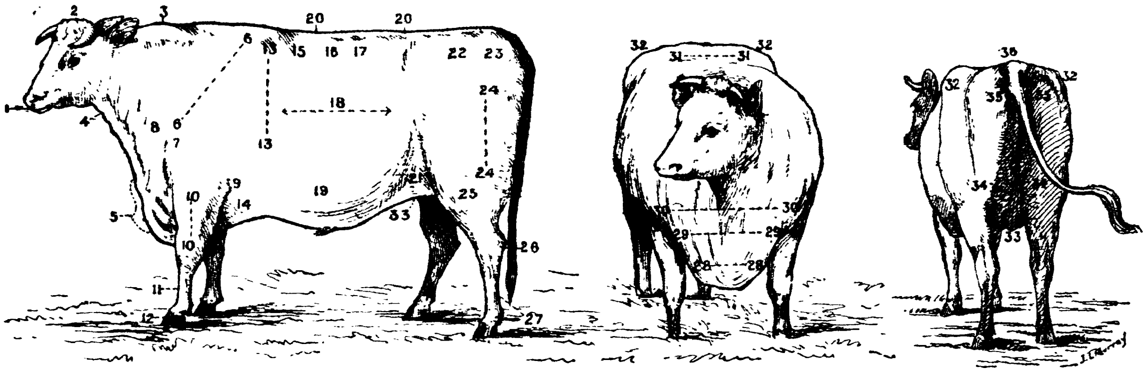


FIG. 33.—Illustrating the Points of an Ox (Thompson)

1. Muzzle
2. Poll
3. Crest
4. Throat
5. Dewlap
6 to 6. Shoulder
7. Shoulder point
8. Shoulder or neck vein
9. Elbow
10. Arm
11. Shank
12. Hoof
13 to 13. Crop
14. Fore flank
15. Fore ribs
16. Mid ribs
17. Back ribs
18. Barrel
19. Belly
20. Spine
21. Flank
22 to 23. Plate
23. Rump
24 to 24. Hip
25. Thigh
26. Hock
27. Hind leg
28 to 28. Brisket
29 to 29. Bosom
30 to 30. Chest
31. to 31. Loins
32. Hooks or hip bones
33. Purse
34. Twist
35. Pin bones or catch
36. Tail-head

not protruding from the general outline of the side nor having a depression behind it; the brisket full, the heart-girth large, and the ribs well sprung or rounded, the middle moderately large, but not "paunchy," and the flank well let down—*i.e.* the underline nearly straight. The animal should be "well ribbed up"—*i.e.* the space from the last rib to the hook should be short; the hind quarters long, wide, level, and fairly square in cut, with the hook bones not too prominent; the plates well filled with flesh, the tail-head level and the tail hanging perpendicularly; the thighs thickly fleshed and the flesh well carried down to the hocks; the twist or inner thigh full. The animal should stand on short legs with fine but flat bone, and with the fore legs placed well apart. The flesh should be firm and resilient to the touch, not soft and flabby; the skin not too thin, but soft and mellow to the touch. "Handling" is very important as an indication of feeding capacity. In judging commercial stores the chief points to look for are "well-bred" heads—*i.e.* showing an approach to the type of some improved beef breed—wide backs, thick flesh, and good middles.

Turning to Milk Production, it is of course true that large cows, on the average, yield more milk than small ones. Moreover, it seems to be true that, on the average, large cows yield more milk in proportion to their total food consumption than small ones. The next point may be illustrated by an interesting analysis that was made by Eckles [1] of the differences between a good and a bad Jersey cow. He found that there was very little qualitative difference in digestive capacity—*i.e.* the two animals extracted practically the same quantities of nutrients from like quantities of particular foods. The maintenance requirement was not quite the same, but in the case in question the poorer cow had the advantage—*i.e.* it maintained its weight when not milking on rather less food than the better animal. In the investigation the cattle were fed for a year in such a manner that their body weights remained practically constant. The important conclusion was that the milk yield was proportional, not to the total ration but to the amount of food eaten over and above the amount required for maintenance; and hence the heavier yielder was also the more economical producer.

If we look for the causes of unsatisfactory yields it is obviously possible that these may be of three kinds. Firstly, certain cattle

[1] See Eckles's *Dairy Cattle and Milk Production.*

milk well for a short time, but "milk down" in condition very rapidly and soon drop off in yield. Here it seems that the mammary capacity may be ample, but the digestive organs are not able to work at sufficiently high pressure to supply the necessary raw materials.

Secondly, there is the type represented in many cows of good beef form. They have ample feeding capacity but the surplus food is diverted to body fat instead of to milk. If a heavy ration be fed to such an animal it continues to fatten up to a certain point, when the appetite declines, the maintenance energy requirement rises, and a balance between the income and expenditure of energy is restored. In this type it may simply be that the mammary system is not of sufficient capacity to deal with the available nutrients, and that, failing an outlet as milk, the surplus nutrients are converted into body fat. This, on the whole, appears likely. On the other hand it is possible that there is a kind of competition for the available nutrients between the fat-storing cells of the body and the mammary cells, and that in animals that have a marked tendency to fatten, the process of storage tends to take precedence over that of milk production. In this last case we should have to regard the fattening tendency as definitely opposed to high milking capacity. Unfortunately there is no evidence on which to reach a definite conclusion. Some deep-milking cattle do, however, fatten readily when dry.

Thirdly, the activity of the mammary tissues depends on the stimulus of parturition, and a new cycle begins with each calving. The yield during the lactation may be determined, to a considerable extent, by the amount of response to this stimulus, which is caused by internal secretions. Hence these secretions may have an important bearing on milking capacity. It has in fact been shown that milk production can be stimulated—even in maiden heifers—by the injection of hormones, particularly synthetic substances such as hexœstrol and stilbœstrol. Experiments have shown that it is possible, by feeding thyroxin, to increase milk yields by several pounds per day over a period of several weeks; but the effect on the total lactation yield is very small.

The importance attaching to the compositional quality of milk depends on the mode of utilization. Where whole milk is sold, all that is ordinarily necessary is that the milk should conform (with a reasonable margin of safety) to the British presumptive

standard of 3 per cent. butter-fat and 8½ per cent. of other solids. Occasionally a market, at a higher price, can be found for milk of superior quality; under the existing milk-marketing scheme special prices are paid for the milk of Channel Island and South Devon cattle. The consumer also prefers milk with a deep creamy colour, which is due to its content of carotene. The colour of milk is partly a matter of the breed and individuality of the cow, but is also influenced by the carotene-content of the food. The yield of butter or of cream depends mainly, and the cheese yield depends very largely, on butter-fat content; so that for these purposes the composition of the milk is important, and attention must be given to the matter in breeding. There is a slight negative correlation between butter-fat content and yield—*i.e.* cattle that give rich milk are generally somewhat smaller producers than those that give poor.

It will obviously be difficult to translate into terms of bodily points the physiological qualities that go to make a good cow, and, as a matter of fact, the judging of milch cattle from their appearance is at best rather an unsatisfactory business. The real test is actual performance, with due allowance for age and the other conditions that are known to affect yield. The mean yield over a series of lactations and under ordinary farm conditions is the best kind of record. Failing this, we must take the record over a shorter period and endeavour to form an impression, from the cow's appearance, of her constitution and general ability to live and thrive in the average environment of her breed.

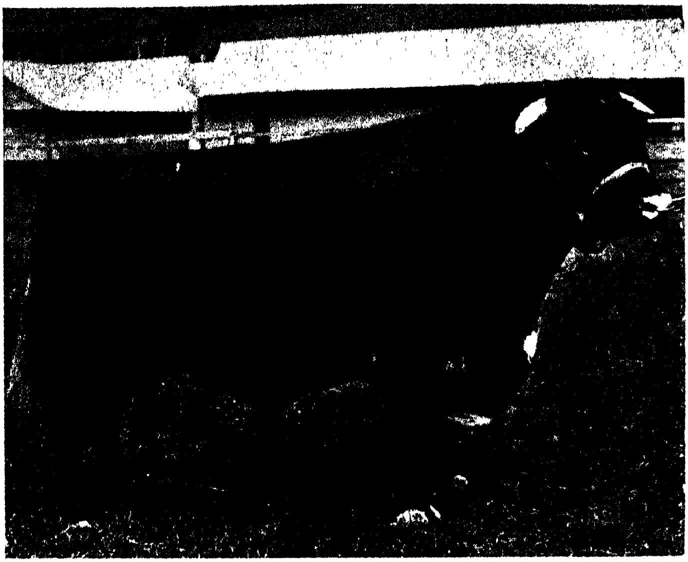
Of the outward signs of milking capacity the most reliable are the size and "quality" of the udder. The udder should be large, extending well forward along the belly and well backwards and upwards. It should also be wide and deep. A pendulous udder, if short and narrow, is often far less capacious than it appears. The udder should be composed largely of actual secreting tissue, which is elastic, so that the udder is large before milking and has a shrunken appearance and a soft, pliable feel when empty. The teats should be placed well apart and be of a convenient size for grasping—*i.e.* say, from 3 to 4 in. long. After the udder, the size of the milk veins, which extend forward from the udder along the belly, is probably the surest guide among the external characters; but it must be remembered that the milk veins become progressively larger with each lactation. A capacious

middle, as showing ability to feed, is also a point of some importance, and a quiet, docile temperament, as indicated by the head, eye, and general behaviour, is desirable.

While no substantial correlations have been established between milk yield and individual body measurements, it has been shown that there is a fairly high correlation between performance and the total "score" for conformation awarded by a competent judge.

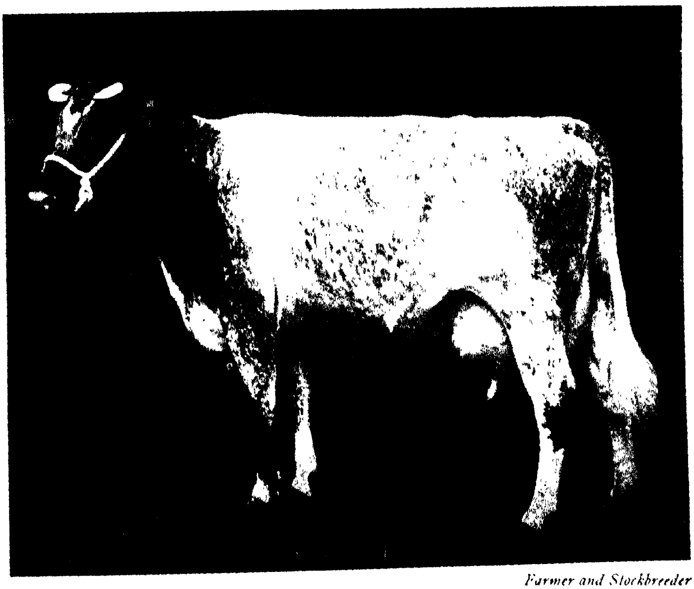
The conventional "ideal dairy cow" has many other points that are considered to be indications of deep-milking qualities, but the value of many of these is doubtful, and there is no conclusive evidence in favour of any of them. Many cows of "dairy type" are good milkers, but others that are poor, as judged by the accepted standards, milk well nevertheless. Briefly, the "ideal dairy cow" is wedge-shaped—*i.e.* she is narrow in the fore end, with sharp withers, and wide in the hind quarters; also, she is relatively shallow in front and deep behind. The horn should be fine and have a waxy appearance, the eye large and placid, the head broad between the eyes—rather longer than in the beef type—and lean; the neck should be long, thin, and muscular, the shoulder light and sloping, the withers sharp and narrow; the chest must be of fair depth and not too narrow, otherwise the animal is likely to be lacking in constitution; the middle should be large, the ribs deep, well sprung, and placed wide apart, with a wide space between the last rib and the hook; the hind quarters should be lengthy and wide, but the hooks not specially prominent; the thighs should be thin and the tail long and fine. Generally, the animal should be thin in flesh, having a somewhat angular but refined appearance; the skin should be thin, soft, and elastic. The colour of the milk is correlated to some extent with that of the skin secretions, as seen, for example, inside the ears and on the end of the tail. Animals that have deep yellow skin generally give deep-coloured, rich-looking milk. Sound legs are necessary if the animal is to have a long milking life. The hind legs should be broad above the hock, and the lower part of the leg should be perpendicular when the cow is standing naturally. The hocks should be wide apart and the gait should be free and easy.

Dairy type is somewhat differently interpreted in the several dairy breeds. The most extreme type is suited only to the best conditions. It is recognised that cattle which are expected to



Farmer and Stockbreeder

A. Shorthorn Bull



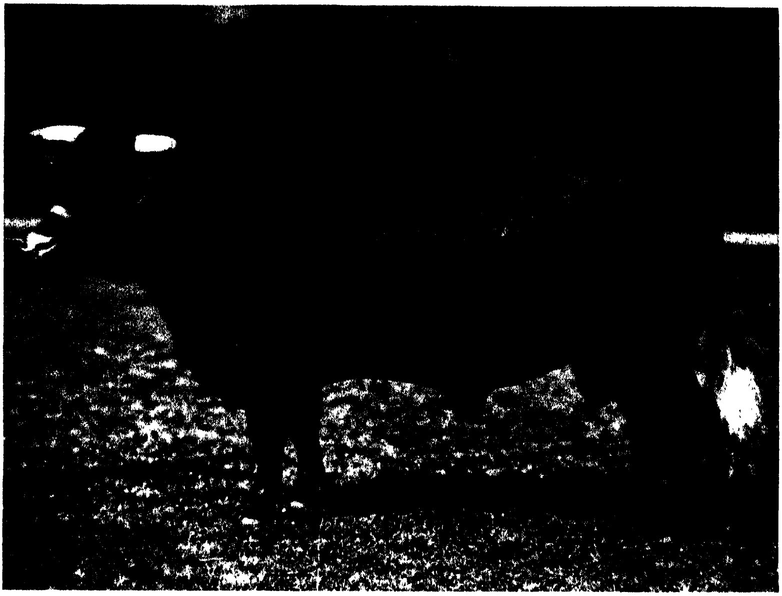
Farmer and Stockbreeder

B. Dairy Shorthorn Cow

G. H. Parsons, Alsager, Cheshire

A. Aberdeen-Angus Bull

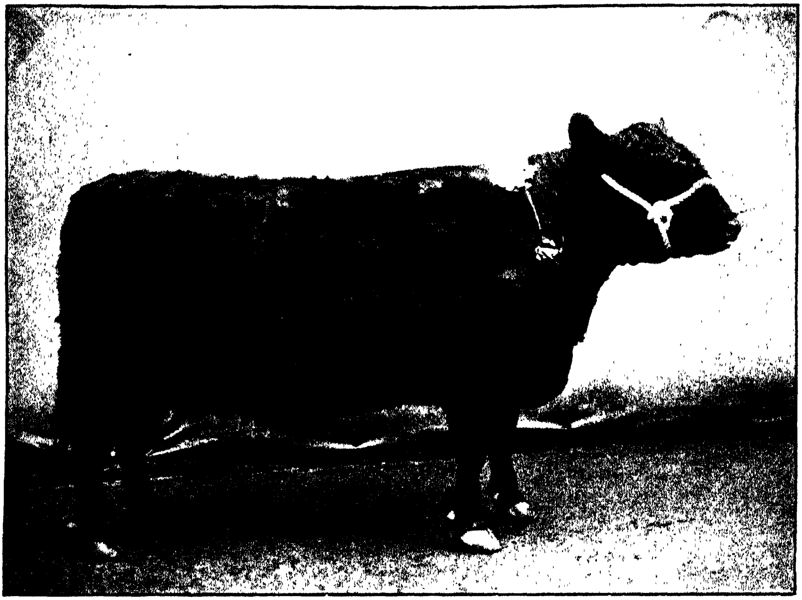
B. Hereford Bull



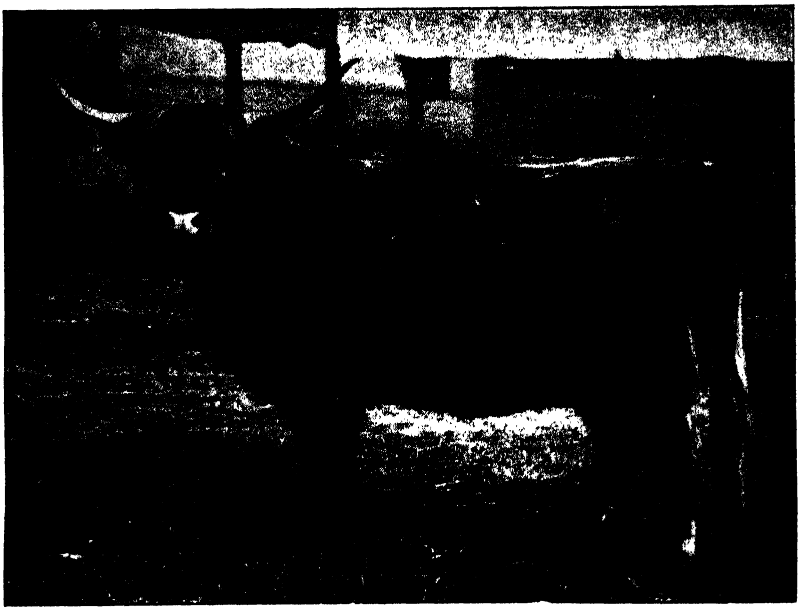
A. Sussex Bull

B. Devon Heifer

PLATE XXXIX



A. GALLOWAY HEIFER



Highland and Agricultural Society

B. WEST HIGHLAND HEIFER

withstand harsh weather or survive periods of scarcity must be rather less refined in form and carry more flesh than the "ideal" dairy cow. Indeed, there is no more important principle in live-stock improvement than that of adapting the type of animal to the conditions under which it has to live. The very productive strains of dairy cattle, like the early-maturing strains of beef cattle, demand a very high level of nutrition. If this is not provided the cow's high productive capacity becomes a danger to herself.

Unreliable as some of the "signs of milk" are when applied to the cow in milk, they are of still more doubtful value as a measure of the hereditary milking qualities in the bull. The most reliable measure of a bull's worth is the performance of his female relatives, whether dam, sisters, or—most important of all—daughters.

The dual-purpose type represents an endeavour to combine milk production in the breeding cow with good fattening qualities in the males and non-milking females of the breed. The recent development of dual-purpose types—*e.g.* in the Shorthorn—has been regarded by some as a retrograde step: they regard specialization as essential to the progressive improvement of live stock and look upon the dual-purpose animal as at best an unsatisfactory compromise between two essentially opposite types. But there is no proof of actual incompatibility between deep-milking qualities and the tendency to fatten when not in milk, and it is, in fact, possible to combine to a considerable extent beef qualities and milking tendencies in the same animal. In any case it would seem that dual-purpose cattle are an economic necessity, for under intensive conditions and with the increasing size of the dairy industry there can be no cheap or abundant supply of store cattle except those bred from dairy cows. The efforts that are being made to fix and perpetuate the combination of qualities are meeting with a large measure of success. A breed, the cows of which give an average yield of the order of 8000 lb. while the steers yield good carcasses at under two years old, would seem to be possible.

BRITISH BREEDS OF CATTLE

There are, all told, twenty-two British breeds of cattle, each of which has its own herd book. No classification can be altogether satisfactory, because each breed shows a certain amount of variation in type from herd to herd, according to the purpose for

which the herd is kept, the method of management, and the fancy of the particular breeder. Thus there have been dairy herds of Herefords and beef herds of Friesians. We may, however, fairly accurately classify the Hereford, Aberdeen-Angus, Sussex, Galloway, and West Highland as beef breeds. The Devon may also be included, but a fair proportion of the cows yield more milk than is required for the normal development of the calf. There are six dairy breeds, the Friesian, Ayrshire, Jersey, Guernsey, Kerry, and Gloucestershire, the last being numerically unimportant. The major dual-purpose breeds are the Red Poll and South Devon, and minor ones are the Longhorn, Belted Galloway, Dexter, and Park. The Shorthorn consists of two main types—the one, represented mainly by animals of Scotch blood, is of extreme beef form, while the Dairy Shorthorn is really a dual-purpose animal. The position is similar in the Lincoln Red Shorthorn and the Welsh Black—*i.e.* each contains beef and dual-purpose strains.

The Shorthorn (Plate XXXVI, *A*) originated in a number of closely related types that existed during the early eighteenth century in Yorkshire, Northumberland, and Durham. The centre of most of the early work of improvement was the area within a radius of about twenty miles of the town of Darlington. The ancestry of these foundation types, while not fully known, appears to have been mixed. The blood of the old black Celtic, of the red Anglo-Saxon, and of the broken-coloured Dutch cattle seems to have been blended in them. There are definite records of importations from Holland as late as 1750, and it is certain that there were many others of earlier date. The cattle of Teeswater, a century and a half ago, were held in high esteem both for beef and milk, perhaps more especially the latter. They were of large size, short horned, and of mixed colours, with red-and-white predominating. The Holderness breed was described in 1743 as having " wide bags, short horns, and large bodies, which render 'em (whether black or red) the most profitable beasts for the dairy-man, grazier, and butcher."

Some careful selective breeding had been done before 1750, but the earliest of the great improvers were the brothers Charles and Robert Colling of Ketton and Barmpton, near Darlington, who began breeding about 1780. They selected the best available animals of the Teeswater type, devoting special attention to fattening qualities, and they inbred very closely. At Charles

Colling's famous sale in 1810 the very much inbred bull "Comet" realized 1000 guineas.

The Booths of Killerby and Warlaby in Yorkshire were also, for three generations, famous improvers. They used Colling bulls in the early stages, and produced a type of animal notable for its substance, wide back and thick flesh, but of little account as a milker. Booth cattle were very prominent in the show-yard, and were highly prized, over the long period from 1840 to 1880.

Thomas Bates of Kirklevington commenced breeding in 1800, and originated a type of Shorthorn that rivalled the Booth in popularity. His ideal was a dual-purpose animal, and he attached great importance to handling qualities, to style and character, and to particular blood lines. He inbred very intensively. Twenty years after Bates's death, which occurred in 1849, his cattle enjoyed a great boom and brought extraordinary prices. After 1890 they fell from favour, but now again Bates's blood is in high esteem among breeders of the dairy type.

The Scotch Shorthorn is mainly the product of the efforts of Amos Cruickshank (1808-95) of Sittyton, Aberdeenshire. He was no partisan of the Booth or of the Bates type, and founded his herd by selecting good animals of very varied breeding, Booth blood, on the whole, predominating. His special aims were a robust constitution, good middle, thick flesh, early maturity, and feeding qualities generally. The Scotch type rose very rapidly in favour—first in the United States and, after 1890, in Britain. It remains the popular type of Shorthorn in beef-exporting countries like the Argentine, and British herds are maintained partly with the object of supplying the demand for bulls to export to these countries.

The last outstanding step in Shorthorn history was made in 1905, when a group of breeders started the Dairy Shorthorn Association, with the object of reviving the original dual-purpose type which at that time seemed to be in danger of extinction owing to the high prices prevailing for animals of the Scotch strain. The Dairy section of the breed has made rapid progress since that date.

All British Shorthorns are registered, without regard to type, in Coates's Herd Book, established in 1822. This is an "open" register—*i.e.* animals are eligible for entry if they have a certain number of registered crosses, and need not be descended from

registered parents on both sides. The regulations require, for females, four crosses of registered blood, and for males five, so that it is possible by the use of registered bulls for four or five generations to grade up non-pedigree herds until all their members are eligible for entry. Any registered animal may compete in the classes for "Shorthorns" at the leading shows, but males can be shown in the "Dairy" classes only if their dams have passed certain specified milking tests. Cows in milk are also required to produce certain minimum yields.

The special breed points applicable to both types are as follows—Colour: red, or red-and-white, or white, or roan. Deep cherry red and deep uniform roans are preferred; patchy roans, red-and-white, and yellowish or gingery red and roan are regarded as objectionable. The muzzle should be flesh-coloured, a black or cloudy nose being very undesirable. The horn is short, laterally flattened, of fine waxy texture, and free from black. It should not curve upwards, but only forward in the male and forward and inward in the female, remaining about level with the crown.

The *Beef Type Shorthorn* (which, in fact, practically means the Scotch strain) is a large animal, exceeded in size only by the South Devon. Compared with that of most other beef breeds the conformation is more nearly rectangular, the back being wide and very flat and the buttock very square in cut. The type shows remarkable early maturity, but the carcass tends to be "wasty" owing to excess of external fat. The cows are in general poor milkers, sometimes yielding insufficient milk for the normal nourishment of their calves. The coat is abundant and the cattle are reasonably hardy.

The great reputation of the Beef Shorthorn rests on its wide adaptability and on its capacity to stamp its characteristics upon inferior types of animal. It has been the universal experience that where the breeder has had of necessity to begin with thin-fleshed, late-maturing "scrub" cows as a foundation, "one cross of the Shorthorn has been equal to two of any other breed." It has been widely used for this purpose in building up the export beef trade of countries like Argentina.

The *Dairy Shorthorn* is numerically very important, but in recent years has been losing ground to the specialized dairy breeds. Mature cows in breeding condition weigh about 1200 lb. The general build, as illustrated in Plate XXXVI, *B*, is deep-bodied

and roomy, with long, level hind quarters, moderately fine shoulders, and broad back. The thighs are more fleshy than in the purely dairy breeds. The udder is capacious, and the present tendency in the showyard is to attach great importance to a square level bag with neatly placed and moderately small teats.

The better herds of Dairy Shorthorns, with good feeding, reach average yields of the order of 7000 to 9000 lb. per annum; individual records of over 10,000 lb. are common, but those over 20,000 lb. are rare. The butter-fat content of the milk probably averages about 3·6 per cent., but in some districts it has deteriorated in recent years. This has been due to the tendency to select for heavy yields without regard to the composition of the milk. In such cases it would be easy to attain higher quality by selective breeding.

An Advanced Register for Dairy Shorthorn cows was set up in 1947. The milk yields required for admission are:—

1. After calving at four years of age or more, at least 10,000 lb. milk and 375 lb. of butter-fat.
2. After calving at three to four years of age, 8500 lb. milk and 330 lb. butter-fat.
3. After calving at less than three years of age, 7500 lb. milk and 300 lb. butter-fat.

Higher yields are required where thrice-daily milking is carried out, and the quantities specified must be produced in not more than 315 days. Cattle accepted for the register must be of good general breed type, and special regard is paid to udder conformation.

Dairy Shorthorn steers, when adequately fed, make good-quality beef at about two years old, and selected animals can be finished at eighteen months. When kept as "stores" until two or two-and-a-half years old, and then fattened, they tend to be too large for the average family-butcher's customers, and are rather rough and bony in conformation.

The Lincolnshire Red Shorthorn, or Lincoln Red, is a strain of Shorthorn found chiefly in its name-county. It is of a whole cherry-red colour, large in frame, and of robust constitution. The Lincoln Red, like the Shorthorn, consists of beef and dual-purpose strains, which are only rarely interbred. Separate classes are provided at the leading shows for cows of the dual-purpose type. The Lincoln Reds are the prevailing breed in many parts

of Lincolnshire, Nottinghamshire, and the adjoining parts of other counties.

The Northern Dairy Shorthorn is a recently formed type for which a herd book has lately been established. Its home is in the Dales of Yorkshire and Durham and the upland parts of Lancashire. It is smaller, more lightly built and more active than the typical Dairy Shorthorn and is said to be better adapted to the hilly land and the rather severe climate. Ayrshire blood has been used in the formation of some of the herds.

The Aberdeen-Angus (Plate XXXVII, *A*) originated in the old local breeds of Angus and Aberdeenshire. As far back as records go, which is to the middle of the sixteenth century, a proportion of these cattle have been black and hornless, characteristics that have now been practically fixed in the breed. Red calves, and others with white markings, are dropped occasionally, but horns have been completely bred out. The earliest improver was Hugh Watson of Keillor, near Coupar-Angus, who laid his foundation in 1808. Of the other breeders in both counties who carried on the work the greatest was William M'Combie (1805-80) of Tillyfour in Aberdeenshire, who not only improved the breed but succeeded in making its merits generally known. The chief breeding district is still the country lying between Inverness and Perth and eastwards to the sea, the breed being restricted, in the more mountainous parts of this region, to the straths and glens. Speyside has very numerous herds. There are now many Angus herds throughout the arable districts of Scotland and also in most counties of England and Ireland. The herd book, established in 1862, is a closed register—*i.e.* no animals may be entered except such as are the progeny of parents already registered.

The Aberdeen-Angus is black in colour, with a brownish tinge in the winter coat and in that of the calf, and with often a little white on the underline behind the navel. It is hornless, with a somewhat sharply pointed poll. The Shorthorn, Hereford, and Sussex all exceed it in size, but the difference in weight is less than it appears, as the Angus is compact and heavy for its size. The Smithfield weights show that the breed is actually about 4 per cent. lighter than the Shorthorn. The bone is small, and the general symmetry and smoothness of outline are marked characteristics. The back and also the buttock are somewhat more rounded than in the Shorthorn, and the hooks scarcely project from the general line of the side.

As a commercial animal the Angus is an early-maturing beef beast of superlative quality. The dressing percentage is high, the carcass is very free from patchiness, and the beef is fine in grain and well marbled. In open competition at the larger fat-stock shows during the past thirty years the breed and its crosses have won more championships than all others together. The yield of milk, though irregular, is high for a beef breed, and cows with really good dairy qualities occur. The temperament is rather more active than that of most beef breeds.

The Angus is particularly well adapted for intensive feeding and for "baby beef" production. It has not proved so widely adaptable as the Shorthorn, nor so useful under poor range conditions as the Hereford. For grading up thin-fleshed and slow-maturing types it is less useful than the Shorthorn, but for imparting quality to herds that are already improved to some extent, it is excellent. Angus bulls are largely used for crossing with cows of dual-purpose type in the production of commercial beef cattle. If still higher quality is required, the cross-bred females may be mated to pure-bred Angus bulls, producing three-quarter-bred progeny. The breed has been an outstanding success under arable or semi-arable conditions—for example, in the maize-growing districts of the United States. It has been exported in large numbers. Mated with a white Shorthorn bull the Angus cow produces the well-known and highly valued blue-grey crossbred.

The Hereford (Plate XXXVII, *B*).—As early as the beginning of the seventeenth century the cattle of Herefordshire were held in high esteem both as work oxen and for beef. They were large, stoutly built, hardy, and generally well suited to be reared and fattened on the fine pastures of the county. Improvement in the direction of early maturity and quality of meat began early. The names of Benjamin Tomkins the younger (1745-1815) and of John Hewer (1787-1873) are the best known—the one amongst the older, the other in a more recent generation of breeders. The herd book was established in 1846 and has been closed since 1883.

As regards Britain, the Hereford is rather a local breed. Most of the prominent pedigree herds are found in the English and Welsh counties adjoining the border, from Cheshire in the north to Monmouth and Gloucestershire. The breed is, however, largely represented in Ireland, and has a large place in the United States, Canada, South America, and Australia. The breed

characteristics are a large size (little inferior to that of the beef Shorthorn), a deep rich red colour (without any black or dark brown hairs), with white head and underline, and generally a narrow band extending along the upper part of the neck and over the crops. Some cattle have a red spot at the eye, which is an advantage in countries of glaring sun. The horn is of medium length, slightly drooping and of a waxy appearance to the tip; the back is wide and thickly covered, the chest deep and capacious, and the legs short. The skin is thick but mellow, the coat mossy and very dense and abundant. The Hereford has not the superlative quality of meat of the Angus, nor is it distinguished, even among the beef breeds, for milking qualities. Its chief value rests in the fact that it has, of all breeds, the fullest combination of early maturing and fattening qualities with a robust constitution. It is an excellent " doer " under pastoral conditions, will fatten readily on good grass alone, and abroad has been found to live and thrive on the poorer and drier type of range where no other improved breed can exist. In their home country the cattle are very generally kept out of doors throughout the year, and as a consequence the breed has always been relatively free from tuberculosis.

The Sussex (Plate XXXVIII, *A*) is native to the Weald district and the marsh lands of Kent, Surrey, and Sussex. The breed was originally kept mainly for draft purposes, and continued to supply work oxen for the Wealden clays long after the horse had become the sole draft animal elsewhere. With changing conditions the Sussex has become a beef breed, but it still bears some traces of its centuries-long use in the plough. In weight it is practically equal to the Hereford, but it is less compact, somewhat more muscular in build, and rather later maturing. The colour is a deep red, the horn fairly large, spreading, light at the base and dark-tipped; the skin is fine and the coat rather short.

The general conformation is that of a good beef animal, the quality of the beef is excellent, and in hardiness and ability to thrive on poor fare the breed is outstanding. It has met with considerable success in South Africa. The herd book was established in 1874.

The Devon (Plate XXXVIII, *B*) is native to the hilly region in the north of Devonshire, but spread at a very early date into the adjoining parts of Somerset. Many descriptions dating from the latter part of the eighteenth and early nineteenth centuries

show that the breed existed in those days in a form not unlike the modern type. The Devons were described by Marshall (1796) as the best workers he had ever seen, and by John Lawrence, in 1805, as having "for a century past commanded the best price at Smithfield." All writers agree that they were hardy, excellent draft animals, and good feeders. Francis Quartly (1764-1856) of Great Champson, Molland, was the greatest individual improver. During the period between 1793 and 1823, when war prices tempted many of the breeders to sell their best cattle and to slaughter their calves for veal, he gradually got together a herd of the best individuals he could find. By continued selection and inbreeding he produced a strain that has since been regarded as the fountain-head of all the best blood.

At the present time the Devon is most numerously represented in North Devon and Somerset, though herds are scattered fairly widely over southern England. On the lower and more fertile pastures of Somerset the cattle are larger and of greater substance, but lack to some extent the refinement of the upland cattle. In appearance the Devon rather closely resembles the Sussex, but is considerably smaller, of a rather brighter shade of red, very frequently with dapple markings. The horns are of moderate length, with an upward tilt in the female. They are of a brownish shade with darker tips. General symmetry of build and smoothness of flesh are marked characteristics. The breed is hardy, well adapted for grazing, and produces beef of choice quality. In recent years more attention has been devoted to dairy qualities, and several pedigree herds are now kept for dairy purposes. In the ordinary showyard, however, Devons are still judged as beef cattle. The breed has met with some success abroad, particularly in semi-tropical countries.

The Galloway (Plate XXXIX, *A*) is an old breed of obscure origin. Two hundred years ago it occupied, to the almost complete exclusion of other breeds, a very large area in the south-west of Scotland. The extension of dairying in this district has caused it to be largely displaced by the Ayrshire, but on the other hand it has extended into the north of England. Like the Aberdeen-Angus, the Galloway is black, polled, and of beef type; otherwise it has few points of similarity with the northern breed. In the Galloway the head is very short, with a broad poll, and with the ears set on rather low; the neck is rather long; the body is deep, but longer and narrower than in the most highly developed beef

breeds. A certain slackness of back and prominence of shoulder are common faults among the ordinary commercial individuals. The skin is thick and the coat very abundant, consisting of a very dense mossy undercoat with an outer covering of long fine hair.

The Galloway is one of the hardiest of breeds, whether under the cold and very wet conditions that obtain in winter among its native hills or in districts of intense winter frosts. The cows of most herds live out of doors throughout the year, being brought to lower ground in winter and returning to the higher altitudes soon after calving. The quality of the meat is excellent, and the carcass is never patchy nor wasteful from excess of fat. In recent years the breed has achieved great success in the carcass competitions at Smithfield Show. The Galloway is, naturally, somewhat slow to fatten, yet wonderful examples of early maturity are often seen at fat-stock shows. Judged by the Smithfield weights, the Galloway is nearly 15 per cent. lighter than the Shorthorn at the same age. The Polled Herd Book was originally founded as a common register for Aberdeen-Angus and Galloway herds, but a separate Galloway Herd Book was started in 1877. A dun-coloured strain of the breed is registered in the same herd book.

Crossed with the white Shorthorn the Galloway produces a " blue grey " that is hardier, if somewhat slower in maturing, than the corresponding Angus cross, and equally esteemed for the quality of its beef. The Galloway is not noted for dairy qualities, though deep-milking cows do occur.

The Belted Galloway is a distinct strain of the breed, separately registered. It has a characteristic white belt round the middle of the body. Some herds are bred upon beef and others upon dual-purpose lines. Dun animals carrying the white belt also occur.

The West Highland (Plate XXXIX, *B*), or Kyloe, is the native breed of the Western Highlands and Islands of Scotland. The recognized colours embrace various shades of red, yellow, dun, and cream, as well as brindled and black, which last formerly prevailed but is now rare. The breed is of moderate size, with large spreading horns and a shaggy coat of straight or slightly wavy hair, and a dense undercoat of a fine woolly texture; the form is square and deep, but somewhat lacking in width. The West Highland is exceedingly hardy and well adapted to live out of doors in the wild and exposed surroundings of its home

country, where it can subsist on the poorest of grazing. It is a slow grower and difficult to fatten until it is fairly mature; indeed the steers are rarely marketed fat until they are three-and-a-half years of age. The beef of well-fattened beasts is of choice quality. The milk yield is low, being little more than sufficient for the rearing of the calf.

DUAL-PURPOSE BREEDS

The Red Poll (Plate XL, *A*) of East Anglia was produced by the blending of two pre-existing local types, viz. the Norfolk Horned, a small and compactly built red beef breed, and the Polled Suffolk Dun, which was much praised by early writers, including Arthur Young, for its exceptional dairy qualities. The blending was carried out on a systematic plan and with the avowed object of producing a "new sort" of dual-purpose cattle. The work began in the first decade of last century, when two breeders, John Reeves and Richard England, both of Norfolk, began on the lines indicated. About the same time a breeder named George, farming in the same county, founded a herd of red individuals selected from among the Suffolk Polled cattle. The breed was first recognised by the R.A.S.E. in 1862, and an admirably conducted herd book was started twelve years later. The Red Poll is still far commoner in Norfolk and Suffolk than elsewhere, but there are herds in almost every part of England and a few in Scotland.

The colour is a uniform red, with frequently some white on the udder of the female, and a white switch. In size the Red Poll equals the Angus, though it carries rather less flesh and is therefore lighter. Horns or "scurs" are not permitted, and a dark nose is regarded as very objectionable; both of these departures from type are rare. Generally the Red Poll is a well-built and symmetrical dual-purpose animal, although the udder is often not so shapely as could be wished. In the past there has been some irregularity of type, due to the varying importance attached by individual breeders to beef conformation and milking qualities respectively, but great progress in the direction of uniformity has now been made. The steers fatten readily at an early age and produce a good quality of beef. In yield and quality of milk many herds compare favourably with those of dairy breeds. Good mature cows will give 8000 lb., and many high individual

records, up to twice this amount and more, have been made. As a "farmer's cow," particularly on moderately poor land, the Red Poll is a valuable animal. The breed is known in the United States and in South America, while there is a growing demand from many of the Dominions, especially the Union of South Africa.

The South Devon (Plate XL, *B*) is numerously represented only in Devon and Cornwall. It differs very markedly from the Devon in being of much greater size. The original colour was a pale brownish red, but the preference is now for the deeper shades. The South Devon is the largest of British breeds, cows in ordinary breeding condition frequently scaling 14 cwt., and bulls in show condition having been known to exceed 30 cwt. The general type, according to the ordinary standard of cattle judges, is rather coarse. Improvement is of comparatively recent date, and a herd book was instituted only in 1891. Milk yields of over 1000 gals. are quite common—several lactation yields of over 2000 have been recorded—and cows of the breed have done well in open milking trials. The average butter-fat content is about 4·3 per cent. and the colour of the milk is a rich creamy yellow. The breed has been largely exported to South Africa, where it is popular on account of its suitability to the climatic conditions and its usefulness for producing trek oxen.

The Longhorn was, in Bakewell's time, very widespread over the west midland and western counties of England, from Westmorland to Somerset and from Shropshire to Leicestershire. The best types were found in Lancashire and in the Craven district of Yorkshire. At the same period the breed was very widely distributed in Ireland, whither it had probably been introduced from England. Before it passed through Bakewell's process of improvement the Longhorn was a large and powerfully built animal that produced good draft oxen and fair milch cows. It had a rough shoulder, flat sides, and large bone, was difficult to fatten when young, and produced a dark-coloured and coarse carcass. At the sacrifice of its dairy qualities Bakewell made it an early maturing beef breed of greatly improved quality, though even in Bakewell's beasts the fat was not well laid on and the meat was poorly "marbled." In the middle part of last century the breed was all but driven out of existence by the Shorthorn. The numbers then increased slowly for a time but are again very small. The breed is now found principally in Warwickshire and the adjoining counties. On the poorer sorts of clay land it has

proved a useful dual-purpose animal. Under these conditions it is hardier than the Shorthorn, and gives a creditable yield of milk of good quality. The breed is of medium size, still somewhat rough in conformation, with long and generally drooping horns. The favourite colour is a dark red brindle, and the characteristic markings include a white stripe along the back, a good deal of white on the underline, and a white spot on the thigh.

The Welsh Black (Plate XLI, *A*).—The black, horned cattle of Wales are of great antiquity, although there is evidence that cattle of other colours have existed in the Principality, along with them, from medieval times. Formerly two breeds were recognised. The North Wales or Anglesey was a hardy, slow-maturing beef breed, well known during the past two centuries as producing the highly valued grazing cattle imported into the Midlands for fattening, under the name of "Welsh Runts." In the south was the Pembroke or Castlemartin breed, rather longer and looser of frame and thinner of flesh, prized chiefly for the dairy. The herd books were amalgamated in 1904, when the breed name of Welsh Black was adopted. Of medium size (about similar in this respect to the Red Poll), the Welsh carries rather long, spreading horns. Show specimens often leave little to be desired in respect of symmetry, but the ordinary run tend to be rather high at the rump, rather weak in the thighs, and hard "handlers." The steers are generally marketed fat at three years old, when they produce a carcass that is full of lean meat and of very high quality. As said earlier, there are varying degrees of emphasis on beef and milk. Some herds are kept like Galloways, the cows suckling their own calves only. Some are crossed, commonly with a Hereford bull, in order to obtain a heavier and earlier-maturing type of store. Other herds, kept on marginal rather than hill land, are kept mainly for milk production.

The Blue Albion has its home in the High Peak district of Derbyshire. It seems to have originated mainly from an admixture of Shorthorn and Welsh blood, but a good deal of Friesian influence can be traced in many herds. The general type approaches that of the Dairy Shorthorn, but the recognized colour (which, however, does not breed true) is blue or blue-roan with more or less white. The breed has something of the hardiness of the Welsh, and many of the cows are deep milkers. A Breed Society was formed in 1919.

Park Cattle.—The Park Cattle or "Wild White Cattle," whose origin has been the subject of much discussion, are now under a Breed Society, have a herd book, and have obtained recognition from the Royal Agricultural Society. The cattle are white with black or red "points." Some herds are polled and others horned. The general type is dual-purpose, and the breed has several records of over 1000 gals. to its credit.

DAIRY BREEDS

The British Friesian (Plate XLI, *B*) is a branch of an ancient breed that has its home in the Dutch province of Friesland, lying north-east of the Yssel Lake (the Zuider Zee). It is only one of several Dutch breeds, but is probably the most highly improved, and certainly possesses the most pronounced dairy qualities. Dutch cattle of the Friesian type have exerted a large influence on other breeds, including our own Shorthorn and Ayrshire, as well as a great number of the lowland breeds of Western Europe. At the present time the Friesian is second only to the Shorthorn in its wide and general distribution throughout the world. The home province consists largely of low-lying and fertile pastures, and the special centre of the breed, the district round Leeuwarden, is one of exceptional fertility, though its climate is distinctly raw and cold.

During the second half of last century large numbers of black-and-white Dutch cattle, both Friesians and animals of the closely related North Holland type, reached Britain. The cows were chiefly bought for town dairies, and only a small proportion were in consequence kept for breeding; but some herds were established in the early seventies and again about 1890. Few of these were kept strictly pure or managed with any particular care, and the breed, as a whole, made little progress until the Breed Society was established in 1909. Thereafter it advanced in favour with extraordinary rapidity, and has continued to increase in numbers ever since. The foundation stock was accepted for the herd book by inspection, and it was impossible to prevent the admission of a proportion of animals of doubtful ancestry. This initial difficulty has since been largely overcome by very strict insistence on the true Friesian markings and type, and by the importation from Holland in 1914, 1936, and 1950, from South Africa in 1922, and from Canada in 1946 of numbers of specially selected animals.

The Friesian is by much the largest of the dairy breeds. The standard colour is black-and-white in clear and distinct patches, though an occasional dun-and-white animal may be seen. A separate herd book has been set up for the red-and-white variety. The feet and switch must be white, and a white star or blaze on the forehead is popular and of frequent occurrence; the head is rather long, the horns short and small, with a forward and inward curve; the neck is rather shorter than in the other dairy breeds; the hind quarters are exceptionally wide, and the animals when young or when out of milk carry more flesh on the back and thighs than do most dairy cattle. The mammary system shows great development and the milk veins are very prominent, but the udder is less square and regular than in the Ayrshire. The breed has sometimes been regarded as rough in conformation and lacking in quality, but these defects are being largely eliminated.

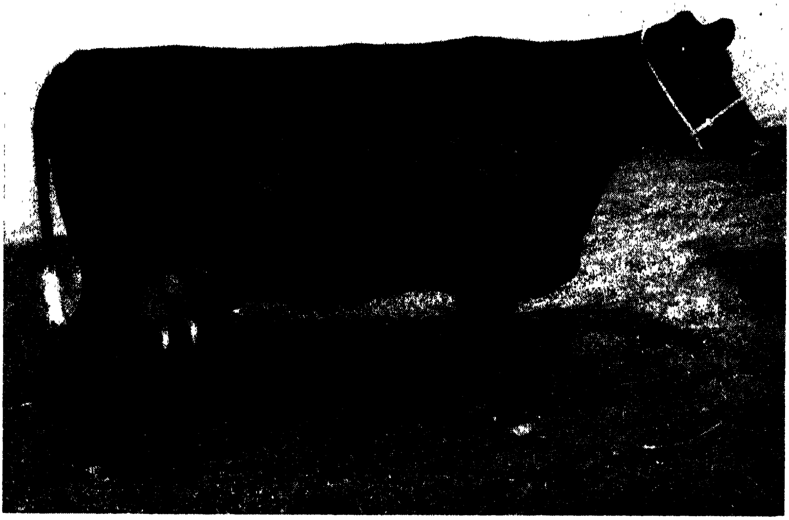
The special merit of the Friesian lies in its great milking capacity. In the United States and elsewhere the breed holds most of the records for quantity, but the record British yield up till 1954 (41,644 lb. in 365 days) was held by a Dairy Shorthorn. In this country many individual yields of from 2000 to over 3000 gals. have been recorded, and large herds have averaged over 1000 for cows and heifers together. One cow of the breed has yielded over 3000 gals. in each of three successive lactations. The breed has provided nine-tenths of the total number of official records of 2000 gals. or better in a year. The fat-content of the milk is commonly lower than with other breeds. In Holland the average was at one time as low as 3·1 or 3·2 per cent. In Britain, while occasional animals fail to reach the 3 per cent. standard, the average would be more nearly 3·4. There is, of course, much individual variation, and a little careful selection will usually succeed in bringing a herd average up to the normal 3·7 or 3·8. Leading breeders are now devoting close attention to the quality of the milk.

As a meat producer the Friesian is the best of the purely dairy breeds, if it be considered as such; but it is not so satisfactory as, say, the recognized type of Dairy Shorthorn. The calves are large and feed rapidly into excellent veal. The steers, unless they are well fed from birth, tend to become too large before they can be fattened out. But if given a good start they provide very useful carcasses.

The Friesian is quite ordinarily robust and hardy, but is pre-eminently suited to the better sort of pastures or to arable dairy farms where food is abundant. On poor upland pastures it has been found that it cannot successfully replace the Ayrshire.

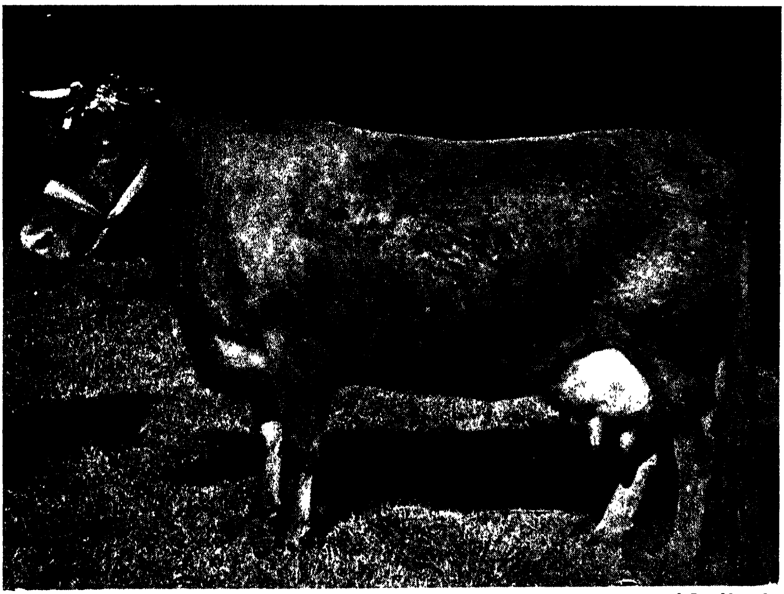
The Ayrshire (Plate XLII, *A*) came into existence some time before the end of the eighteenth century, but of the methods by which it was evolved we have no clear idea. The native cattle before the new improved breed displaced them were miserable beasts, "few of the cows yielding more than from 1½ to 2 gals. in the day, at the height of the season, or weighing when fat more than 20 st." Teeswater—*i.e.* early Shorthorn—cattle were imported, and possibly other cattle of more immediate Dutch extraction. There are traditions, too, of "Alderney"—*i.e.* Channel Islands—cattle having been introduced. The centre of improvement was the parish of Dunlop, and John Dunlop of Dunlop was one, and probably the greatest, of the early breeders. The breed, as it spread over the northern portion and finally over the whole of the county, was successively known as the Dunlop, the Cunningham, and the Ayrshire. It began to be generally recognized as a distinct and improved breed about 1800, and has ever since been famous as a milker. Thus among the less extravagant estimates of the average yield is that of Sir John Sinclair, who, in 1813, reckoned it at 900 gals., and that of Low, in 1845, who states that "healthy (mature) cows on good pasture" should give between 800 and 900. In the beginning of the present century some strains of Ayrshires deteriorated owing to the neglect of dairy qualities for purely "show" points. On the other hand, the milk-recording scheme initiated by John Speir, in 1903, has had a very beneficial effect on the utility qualities of the breed.

The Ayrshire is a comparatively small breed, cows in ordinary breeding condition scaling between 8½ and 9 cwt., or, say, four-fifths of the average Friesian weight. Cattle on poor upland farms are, of course, lighter than those found in the more fertile districts. The colour is red or brown with a varying amount of white—a large proportion of white being fashionable. Black-and-white, which is not uncommon among commercial cattle, is an accepted colour, but is not in favour with pedigree breeders. The horns are rather large, set fairly wide apart, and have a very characteristic upward curve. The conformation is very



Farmer and Stockbreeder

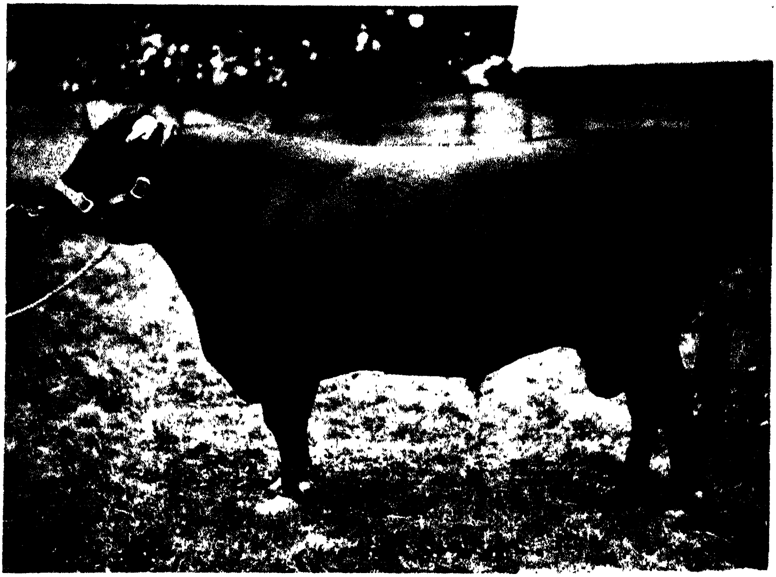
A.-Red Poll Cow



Farmer and Stockbreeder

B. South Devon Cow

PLATE XLI



C. Reid, Wishaw

A. Welsh Black Bull

Farmer and Stockbreeder

B. British Friesian Cow

A. Ayrshire Cow

Farmer and Stockbreeder

B. Jersey Cow

Farmer and Stockbreeder

A. GUERNSEY COW

Farmer and Stockbreeder

B. KERRY COW

symmetrical and neat, the back being straight and the lines of the body smooth. The udder is also characteristic, being of great length and width, firmly attached (not pendulous), level in the sole, with small teats squarely and neatly placed. At one time the fashion for "tight vessels" and small teats was carried too far, but the modern show standard is quite compatible with high production.

On the poorer sorts of land, at high elevations and in cold climates, the Ayrshire is a very valuable dairy animal. The general average of all the yields recorded in recent years is over 650 gals. with about 3·8 per cent. of butter-fat. Many herds (whole herds, including frequently 20 or 25 per cent. of heifers) have averaged over 800 gals. with a butter-fat content of 4 per cent. or better. Individual yields of 1000 gals. and over are common, so that, in view of its small size, the Ayrshire must be regarded as a highly economical producer of milk. The fat globules are small, so that the milk "creams" slowly, which is an advantage for cheese-making. For beef the Ayrshire is of little account. There is a general consensus of opinion that the male calves are neither worth rearing for beef nor feeding for veal, although the quality of the finished steer is fairly satisfactory.

Ayrshires are largely kept in Canada and the United States, Sweden, South Africa, and New Zealand.

The Jersey (Plate XLII, *B*), which is believed to be of French origin, has existed on its native island for centuries, and no foreign blood has been permitted to be introduced since 1763. A mild and equable climate and a fertile soil render the island very suitable for intensive dairying.

The Jersey is a small breed, the average weight of mature cows being probably under 7½ cwt. The colours are fawn, silver grey, brown and brownish black, either whole or more or less broken with white, and with a characteristic "mealy" ring round the muzzle. The horns are small, with an inward curve, and the head is lean and refined, with the orbits very prominent. The cows are generally very "wedge-shaped" and thin-fleshed, and have an angular but refined and deer-like appearance; the skin is thin and the hair short; the udder is generally both capacious and symmetrical, and the milk veins very prominent. The quantity of milk produced is fair, perhaps good, in relation to the size of the animal. The butter-fat content is very high, averaging

somewhat over 5 per cent. The fat globules are large and the milk is deep in colour, so that it creams rapidly and has a rich appearance. As a beef animal the Jersey is of no account.

Under favourable conditions of climate and food the Jersey is greatly prized as a butter cow, and she is also a commercial success where there is a sufficient demand, at a special price, for a high quality of milk. The Island herd book was established in 1866 and a separate English register in 1879. Abroad the breed is most numerously represented in the United States, Australia, and New Zealand.

The Guernsey (Plate XLIII, *A*), under which name are included the cattle of Guernsey, Alderney, Sark, and Herm, is a larger, less refined, and (in keeping with the less favourable climatic conditions of its home) a more robust breed than the Jersey. The colours are various shades of fawn—red, yellow, and brown—the first predominating; white markings are more frequent than in the Jersey. A light or buff-coloured muzzle is preferred, but dark noses are fairly frequent. The skin is of a very deep yellow colour, and the deeper shades are preferred.

Compared with that of the Jersey, the general conformation is rougher. The shoulder is more loosely attached, the wither is thicker, and the thighs rather fleshier. A certain amount of slackness of back and a prominence at the tail head are common faults. The Guernsey is a fairly deep milker, good herds averaging perhaps 700 gals. The butter-fat content of the milk is slightly lower than that of the Jersey—probably about 4·8 per cent. on the average—but the milk and butter are richer in colour than those produced by any other breed. The Guernsey grows rather longer and reaches maturity more slowly than the Jersey, which latter is often bred from at a very early age. The bulls, as is common in the case of the other small dairy breeds, are treacherous and troublesome to handle, though here, again, the Jersey is the more extreme type. For veal production Guernsey calves have some little value. The steers, however, mature very slowly and are of poor quality, with an objectionably deep yellow-coloured fat. Few steers are reared. The Guernsey is fairly hardy, and thrives in quite exposed situations without exceptional precautions as to shelter or food. There are both Island and English herd books. The breed has been largely exported, the United States being the principal market.

The Kerry (Plate XLIII, *B*) and the **Dexter** are the only remaining native breeds of Ireland. The Kerry is an ancient breed, small in size, neatly built, active and hardy, standing on rather long legs and of distinctly dairy type. The colour is black, with frequently a little white on the udder of the cow. The horns are of medium length, rather thin, and curve upwards. On poor hill pastures the Kerry is a commercially useful breed, and gives a creditable yield of milk of rather better than average quality.

The Dexter is of whole black or whole red colour, and of a distinctly dwarfish conformation, with short legs and a heavy head. The general build is compact and blocky, and the breed is a dual-purpose one. The Smithfield figures show that the breed attains rather less than 60 per cent. of the average Shorthorn weight. Crosses with Angus and other beef breeds make excellent small butchers' cattle. Monstrous calves, of the so-called "bull-dog" type, are much commoner than in other breeds. Indeed, the Dexter appears to be a heterozygous form, producing, when bred pure, 25 per cent. of long-legged "Kerry type" calves, 50 per cent. of true Dexters, and 25 per cent. of "bulldog" calves.

The Old Gloucestershire is a breed of dairy cattle, brownish black in colour, with a white line extending along the middle of the loin and rump and over the tail head. It has been preserved in very small numbers, but a society was formed in 1919 with the object of reviving it. So far no very great progress can be recorded.

COMMERCIAL TYPES AND CROSSES

There is agreement among live-stock authorities that the quality of British cattle, and indeed of British live stock in general, suffers harm from the large amount of indiscriminate crossing that takes place. Some improvement in the situation has occurred since the initiation of bull licensing schemes, under which all young bulls are required to be presented for inspection to officials of the Agricultural Departments. Those that fail to exhibit a reasonable standard of merit are refused licences and have to be either castrated or fattened for slaughter within a specified time. The system was revised in 1945 with the aim of encouraging systematic breeding. A dairy licence is granted only to a bull whose dam and paternal grand-dam have yielded stipulated

quantities of milk under official milk-recording. A beef licence is granted only to animals belonging to a recognized beef breed and of good individual conformation. General licences will continue to be granted only until a sufficient supply of dairy and beef bulls becomes available.

The following are some of the better types of cattle that are available in quantity, with the main breeding areas in each case :—

1. *Store Cattle suitable for Fattening at Young Ages.*—Grade or pure-bred Herefords from the Welsh Border area and from Ireland; grade Aberdeen-Angus and crosses between Angus and Beef Shorthorns from the semi-upland areas of Scotland and from Ireland; Devons from Somerset and Devon.

2. *Stores for Fattening at Intermediate Ages.*—Crosses between Hereford or Aberdeen-Angus bulls and cows of Dairy Shorthorn type from many areas; crosses between Hereford bulls and Welsh Black cows from semi-upland areas in Wales; South Devons and Sussex from their respective home districts; the fleshier types of Dairy Shorthorns from Ireland and northern England; Friesian steers from lowland areas generally; crosses between White Shorthorn bulls and Galloway cows (Blue Greys) from south-west Scotland and northern England.

3. *Stores for Fattening, mainly on Grass, at Older Ages.*—West Highland and Shorthorn-Highland crosses from the Scottish Highlands; Galloways from south-west Scotland, Cumberland, and Northumberland; Welsh Black from the mountain regions of Wales.

4. *Dairy Heifers.*—Ayrshires from Lanarkshire, Ayrshire, Dumfries, and Wigtown; Dairy Shorthorns from Cumberland, Westmorland, Yorkshire Dales, etc., from Somerset and Wiltshire, and from Ireland; Jerseys, Guernseys, and Friesians from lowland areas generally.

5. *Beef-type Calves.*—Single-suckled beef calves are produced mainly in the hill and "marginal" districts of Scotland, northern England, and Wales, and are commonly sold at special auctions in October. The common types are Welsh Black, Herefords, and crosses between the two; Galloways and "Blue Greys" (from Galloway cows by a White Shorthorn bull); West Highland and Shorthorn crosses; and Angus and Angus-Shorthorn crosses. Another useful type includes "colour-marked" calves, mainly crosses between Dairy Shorthorn and Friesian cows by Hereford

or Aberdeen-Angus bulls. Such are usually sold at the age of a few days.

BREEDS AND NUMBERS OF LICENSED BULLS

The relative numerical importance of our breeds is shown in the following table, which gives the numbers of bulls licensed in (1) the year about the beginning of the war and (2) the last year for which figures are available:—

Breed	England and Wales		Scotland	
	Year ended 31.3.39	Year ended 31.3.53	1939	1952
Aberdeen-Angus	783	478	1,395	1,345
Ayrshire	554	2,365	3,830	3,591
Blue Albion	32	11	...	...
British Friesian	3,086	7,110	219	490
Devon	1,128	656	...	2
Dexter	16	23	...	2
Dun and Belted Galloway	6	6	232	18
Galloway	241	76	..	264
Gloucestershire	3	4	...	...
Guernsey	1,544	1,379	10	8
Hereford	2,351	1,524	6	132
Highland	4	6	42	81
Jersey	498	661	18	46
Kerry	14	13	...	...
Lincoln Red Shorthorn	1,300	1,045	...	1
Longhorn	5	...	...	...
Park (British White)	14	7	...	1
Red Poll	536	542	4	17
Shetland	2	...	20	7
Shorthorn	23,807	13,290	1,272	814*
South Devon	449	531	...	...
Sussex	238	157	...	...
Welsh Black	440	412	...	1
Crossbred	34	1	2	...
Total	37,175	30,297	7,050	6,818

* Including 177 Dairy type and 3 Poll Shorthorn.

In Northern Ireland the numbers licensed in 1952 were: Shorthorn and non-pedigree Shorthorn, 1262; British Friesian, 223; Ayrshire, 131; Aberdeen-Angus, 121; Hereford, 93; and Galloway, 23, with very small numbers of other breeds.

CHAPTER IV

BREEDING AND REARING OF CATTLE—MILK AND BEEF PRODUCTION

THE age at which heifers should first be mated depends on their breed, on their individual characteristics, and on the system of feeding and general management to which they have been subjected during the earlier part of their lives. Females of the early maturing beef breeds, such as the beef Shorthorn, are sometimes, if they be well grown, mated at fifteen months of age, so that they calve down at two years old. Jerseys are frequently put to the bull quite as early. With breeds like the Dairy Shorthorn—which are about average in rate of growth and development, and are suited to average conditions of food and housing—the ordinary age at first service is about twenty-one months, bringing the first calf at thirty months. It is to be noted, however, that where there is a fixed breeding season—as, for example, in pedigree beef herds, cheese dairies, etc.—the choice will fall to be made as between mating at about fifteen months or twenty-seven months so that the heifer may calve in proper season either at two years or at three years old. Again, in whole-milk selling farms it is usually necessary to have a large proportion of the heifers calving in autumn, in order to secure a uniform output of milk throughout the year; and on this account the age for mating may be varied from that which would otherwise be chosen. Animals of the later maturing breeds (Galloway, Welsh, etc.) should not ordinarily calve before they are three years old, and on the poorest Highland grazings West Highlanders are sometimes not calved down till four. Heifers have been known to take the bull, and to conceive, at as early an age as four or five months, so that they must be kept apart from bull calves from this age until they are considered sufficiently developed to be served.

In view of the many variable factors no precise statement can be made about the optimum age for first mating, but two general points must be borne in mind. First is that gestation makes comparatively small demands upon the heifer's system, whereas lactation, in the case of deep-milking animals, makes very heavy demands. Hence an animal that is producing a

considerable amount of milk at the age when rapid growth should still be going on, requires a highly concentrated ration if the combined needs for maintenance, growth, and milk production are all to be met in full. If they are not met the animal will be stunted permanently.

On the other hand there is a widespread belief, which has some support from experimental evidence, that delay in mating may prevent the full development of the inherent milking capacity.

Bulls of the earliest maturing breeds may begin to be used at ten or twelve months old; those of average development at about fifteen months. Sixty cows may be put as a maximum allotment for a bull of two years old or over, but much depends on the length of the breeding season, which may extend over two or three months only or may cover most of the year. Breeding bulls must be kept in active and thrifty condition by arranging for sufficient regular exercise, and by so adjusting the ration that the animal is kept in healthy condition without becoming fat.

The ordinary duration of life in cattle is twelve to fifteen years and there are many records of individuals surviving to eighteen or twenty. The average useful life of the dairy cow is very much shorter owing to such troubles as sterility, mastitis, and tuberculosis. The average milking life is about four lactations.

The average period of gestation is 280 days. Œstrus generally begins to occur at from five to eight weeks after calving, so that it is possible for a cow to bear successive calves at intervals shorter than a year. Where all-the-year-round breeding is carried on the period between successive calvings, however, may average about thirteen months. When the calves are wanted at a particular season—*e.g.* March to May in the case of commercial beef-breeding herds—the number of living calves may reach 90 per cent. under good conditions and in the absence of any exceptional factor such as contagious disease. Under the poorest conditions—*e.g.* on mountain grazings—2 weaned calves from every 3 cows may be regarded as a satisfactory result.

The interval between successive "heats" varies a little, the average being about twenty days. Females in good condition come in "season" at all times of the year, but most regularly in spring and summer, and least regularly in late autumn and early winter. The length of the heat period is on the average about eighteen hours, but it varies between six and thirty hours. Œstrus is shortest in mid-winter when it may easily pass unobserved. In

the case of cows running out on pasture without artificial feeding, œstrus may occur only during the summer months. Unsuccessful matings are somewhat common and are due to a variety of causes. In the absence of widespread contagious disease among the cows, and with a fully fertile bull, about two-thirds of the cows may be expected to conceive to the first service. Twin calves are fairly rare—rather above 1 per cent. in dairy herds and about half of 1 per cent. in beef herds. Fertility in the bull depends upon the number and the activity of the sperms, and these vary over a wide range. Bulls may be infertile, either temporarily or permanently.

Calf Rearing.—The first period of the calf's life—extending to perhaps six months, when under natural conditions it would be receiving its dam's milk—is one requiring somewhat special consideration. The methods of feeding and general management vary greatly according to economic conditions—such, for example, as the local value of milk and milk products, the cost of labour, the rent of the land, and the probable commercial value of the calf itself.

Certain general principles must, however, be observed under all conditions if ailments and deaths are to be avoided. These are :—

1. The calf's powers of resistance to the commoner infections —those that cause white scour, joint evil, and pneumonia—are greatly reduced if it be deprived of the colostrum of the dam. The main explanation is that the colostrum contains " immune bodies " that confer protection against the particular strains of *Bacillus coli* that happen to be prevalent in the premises at the time when the calf is born. In cases where a cow has died in calving or has failed to come into milk immediately, the calf's chances of survival are reduced unless some substitute is provided or exceptional measures are taken to prevent infection. Colostrum from another cow in the same herd (either recently calved or approaching calving) is the best substitute for that of the calf's own dam. The maintenance of a stock of colostrum in deep freeze may also be a useful insurance.

2. Colostrum can be a rich source of vitamin A (and carotene); hence the cow, for some weeks before calving, should have a reasonable supply of green food, low-temperature silage, etc. The same materials will provide a stock of vitamin E, a deficiency of which is the cause of muscular dystrophy. Another point is

that, whereas colostrum forms a soft curd, that produced from the milk of a " stale " cow gives a hard curd. Such milk, if given during the early days of the calf's life, should be diluted with warm water.

3. In order to prevent infection through the open navel, this should be dressed daily with iodine until it dries up.

4. Calves when housed should be kept singly or in small lots in clean, well-littered pens, so as to restrict the spread of disease.

5. Pail-fed calves should have at least three meals of milk daily for the first ten to fourteen days.

6. A calf on an ordinary allowance of milk will drink up to a gallon of water per day, and water should be freely offered.

7. Easily digestible concentrates and hay of the best available quality should be offered earlier than is the usual practice—from the age of about a fortnight.

8. At the first sign of digestive disturbance milk should be withheld for twenty-four hours, and milk diluted with water should be fed for the following day or two. If there are signs that hard curd is being formed in the stomach, an ounce of sodium citrate solution (15 per cent.) should be added to each gallon of milk fed.

9. The general level of feeding during the first few months of the calf's life should be sufficient to support full growth. The consumption of a large amount of coarse fodder, induced by a shortage of milk or concentrates, produces a characteristic lean-backed and pot-bellied appearance.

Veal production, as being a matter rather apart from rearing, may be dealt with first. Surplus calves of the smaller dairy breeds, such as the Ayrshire and Jersey, are frequently slaughtered within a few days of birth. Such animals are, however, of very little value, bringing frequently no more than a few shillings apiece. In some cases the whole carcass is used in the manufacture of dog-biscuit, etc., while in others part is used for manufactured products such as veal loaf. Calves of the Friesian or Dairy Shorthorn type—or, say, Ayrshire-Shorthorn crosses—are, on the other hand, quite suitable for the production of good veal. The average age for marketing may be taken as six weeks, but a good product may be secured at any age from four to twelve weeks. Later the flesh takes on more or less of the character of beef, and the price obtained is less. In the meat trade the term " Bobby " is used to describe a calf of less than three weeks of age, and

therefore necessarily of somewhat inferior quality. The term "Runner Calf" is applied to an animal which, whether by reason of excessive age or the method of feeding employed, has lost the pale colour of flesh that is found in a true veal calf. In order to produce a high quality of true veal the animal should, during the short period available, be kept fattening rapidly, and to this end it should be closely confined and heavily fed. In order to prevent its taking exercise it is generally placed in a small and partially darkened pen, which must be kept clean and regularly littered. Commencing with about 1 gal. daily of colostrum (the first milk of its dam) divided into four meals, the calf should, by the end of the first week, be receiving ½ gal. thrice daily. This is still further increased, until by the end of the period the ration may be anything from 2 to 3 gals. daily, according to the animal's size. With such treatment a calf weighing 80 lb. at birth may be expected to make a steady live-weight increase of 2 lb. per day, and will thus, at the end of six or seven weeks, scale about 170 lb. live weight and yield about 100 lb. of veal. The quantity of milk required to produce 1 lb. of live-weight increase, when the calf is receiving a full ration, rises from about 8 lb. at the beginning to about 12 lb. at the end, and averages perhaps 1 gal. (10 lb.).

When butter-fat has a high commercial value, as is usually the case, fair results may be obtained on a ration consisting, to the extent of as much as a half, of separated milk plus a cream substitute (see *infra*). Veal calves are not castrated.

The methods of rear that are adopteding for animals destined for beef, for the dairy or for breeding, may be classified somewhat as follows: (1) The *natural* system, in which each cow suckles her own calf; (2) the *semi-natural*, where a cow suckles two or more calves during a lactation period; and (3) the *artificial*, where the calf is pail-fed, usually, in part at least, on some substitute for whole milk.

1. The natural method of rearing ordinarily produces the best calves, and the chief ground for departing from it is its high cost. With deep-milking cattle the method is, of course, not applicable, even when the value of the calf might justify it, because the quantity of milk produced is greater than the calf could take. The natural system is universally adopted in the better herds of pedigree beef cattle, where the value of the calf may ordinarily be expected to cover the whole cost of maintaining the cow for the year. In such herds, in fact, the bull calves, if they are intended

for early sale, are sometimes transferred, at the age of five or six months, from their own dams to freshly calved and deep-milking nurse cows, or may be allowed to suck both. In the production of commercial beef cattle the system is mainly confined to districts where cheap, rough grazing is available, and where the cows can be kept out of doors and look after themselves for the greater part of the year. Galloway and West Highland cows are suitable for this purpose in bleak districts, and Hereford or Sussex where the climate is less rigorous. The first two breeds will generally be crossed, if conditions permit, with the beef Shorthorn, in order to obtain larger and earlier maturing calves. Angus cows, kept on better land and housed in winter, are sometimes used in a like manner, and the value of the calves (for intensive feeding into "baby beef") is very high. The increased cost of maintenance of the cow is, however, a disadvantage. Commercial beef calves are normally born in late winter or spring, and are usually weaned in October.

2. It may be reckoned that, with careful treatment and suitable additional feeding, good commercial calves suitable for early fattening can be reared on about 150 gals. of whole milk—sufficient, that is, to allow a gallon and a half daily for the first hundred days of the animal's life. It is obvious, therefore, that a reasonably deep-milking cow may be made to rear four calves in a season, and a good milker as many as five or six. Even if we allow a longer suckling period, in order to avoid some of the difficulties, and even if we aim at the production of really well-conditioned calves suitable for "baby beef," an average cow of dual-purpose type should be capable of rearing two or three annually. Again, it is possible, by the use of suitable calf meals containing a proportion of dried separated milk, to adjust the number of calves so that each will get 1 to 1¼ gals. per day. A deep-milking cow (yielding say 5 gals. per day after freshening) may nurse 4 calves for the first three months, 4 more during a second period and 2 more in a third, making 10 in all. The essentials for the success of the system are skilled supervision, a supply of suitable calves, and the collection of a herd of cows that not only milk well but accommodate themselves to the scheme of management. Some cows, even when they are quiet to milk, will refuse to suckle other calves than their own, while others show almost complete indifference. Refractory animals should be disposed of or transferred to the dairy.

When not more than two calves are to be suckled, close supervision is necessary only during the early stages. After the first few weeks the cow and calves may be put to grass with the reasonable expectation that all will go well. Milk will at first largely satisfy the calves' appetites, and their intake of grass will tend to keep pace with the development of the paunch. If, however, the cow is to have three calves during the first part of the lactation, if these are to be weaned and replaced by others in the middle of her milking period, and the process perhaps repeated a second time, the supervision must be close and constant. Here it is necessary to keep the calves in pens or paddocks and to bring in the cows twice a day to suckle under the eye of the herdsman.

The purchase of young calves on the open market involves the danger of introducing disease—particularly white scour—and therefore such should be kept apart from the rest of the herd for a week or two. In view of what has been said above on the importance of colostrum, it is generally unwise to buy calves that are less than ten days old, unless the buyer has a freshly calved cow available.

In some cases white scour, which is generally due to invasion of the system by some form of *Bacillus coli*, may cause heavy loss. The point has already been made (see p. 616) that a cow passes on to her calf, in the colostrum, resistance to the types of *Bacillus coli* that happen to prevail in the place where she is kept. But a calf that is moved to another farm will probably be exposed to different types of the organism, so that white scour may occur despite ordinary care in feeding and sanitation. Dosage with sulfaguanidine is very effective both as a preventive and as a cure. As a preventive, a dose of 2 gm. may be given shortly after the first feed of colostrum, with a second some six to eight hours later. Similar doses should be given morning and evening for the following two days. Affected animals may be treated by dosage at four- to six-hour intervals. The first dose should be 6 to 7 gm., the second 4 to 5 gm., and the subsequent ones 3 to 4 gm., varying with the size of the calf. Dosage should be continued until the scouring ceases.

When the cows are made to suckle successive batches of calves, weaning is necessarily both sudden and abnormally early, and hence every endeavour must be made to induce the calves to eat a good ration of concentrated food as the time for weaning

approaches. They should commence with a small amount of nutritious and palatable concentrate before they are three weeks old. A mixture of three parts oats or flaked maize, two parts finely broken linseed cake, and one part of fish meal is suitable, and the quantity should be raised, if possible, to 1½ lb. before weaning, and to perhaps 2½ lb. immediately after. The calves should have some good hay from the age of two weeks, and in winter, from the age of three or four weeks, some finely sliced roots. Later on the supply of concentrates may be augmented, up to a total of 3 or 4 lb. per head per day. Calves that go to grass before they are six months old should continue to receive a little concentrate even if the grazing is very good. If the pasture is of only moderate quality the feeding of concentrate should continue till the age of six or eight months.

3. Pail-feeding has, generally speaking, the object of permitting the partial substitution of other materials for whole milk. In pedigree dairy herds, bull calves and sometimes heifers also are fed by the pail on whole milk only, the objects being to obtain the milk records of their dams and at the same time to regulate the ration; but such a mode of feeding is not general. Separated milk, which has half the energy value and contains all the protein and ash of the natural milk, may be available to the farmer at a fourth of the price of the latter or even less. If separated milk is not available on the farm, separated milk powder may be mixed with warm water at the rate of 1 lb. to the gallon. Whey, which has nearly one-third of the feeding value of milk, can generally be utilized only as animal food, and can be used, with a fair measure of success, in the rearing of calves. Commercial "calf-starters" containing substantial amounts of dried separated milk with vitamin concentrates, etc., enable a considerable economy in whole milk. Pail-feeding is the normal system in dairy herds and, in fact, generally where intensive farming is carried on.

Whatever substitutes are to be fed ultimately, the calf should have its mother's milk for ten days if possible, and at any rate for some time after it has lost the obvious qualities of colostrum. Whole-milk feeding[1] should be continued, if at all possible, for two or three weeks more, the quantity fed being increased from 1 gal. at first to 1½ gal. later—more or less according to the size

[1] The milk of certain Channel Island cows is too rich for their calves. In this case it should be diluted with about 25 per cent. of water.

of the calf. After that time substitution may begin, but should be gradual at first, and should be spread over a further period of two or three weeks. Where separated milk is used, the additional food—the butter-fat substitute—need supply only the energy and the vitamins (A and D) that butter-fat provides. It must be in a readily assimilable form, but apart from this it is a matter of indifference whether it consists of oil, starch, or sugar. Fats and oils, though formerly much used, are generally unsatisfactory when used in quantity. In crude liquid form they cause digestive disturbances, and in finely emulsified form they are too expensive. Cod-liver oil, formerly given as a source of vitamins A and D, is best avoided, since it has an anti-vitamin E effect, and the essential vitamins A and D can be supplied in pure form. Crushed linseed, oats, and flaked maize are all good, the two latter being preferable on account of their cheapness. Oats need not be crushed or ground; indeed, young calves seem to prefer whole oats, and masticate these quite thoroughly. The cereal meals should be used at the rate of about ¾ lb. to each gallon of separated milk. If possible, the milk should be fed quite fresh, being separated immediately after milking and given to the calves while still warm. Skim milk, while richer in fat than the mechanically separated article, has the disadvantage of being somewhat stale. In any case, it should be raised to blood temperature before being fed and should preferably be in sweet condition. With separated milk and a fat-substitute a live-weight increase of 1½ lb. daily may be taken as normal.

Where separated milk is available in large quantities, good results may be obtained by substituting 2 gals. of this for 1 gal. of whole milk, adding a source of A and D to make good the vitamin requirements. The calves seem to suffer no harm by reason of the very high protein intake which this method implies.

Whey differs from separated milk in that it lacks not only the fat but also the casein and part of the ash. Moreover, it has necessarily developed some degree of acidity. In order to stop the lactic fermentation, the portion of the whey that is not to be fed immediately it is drawn from the vats should be scalded and cooled. It must be reheated to blood temperature before use. Freshly drawn whey is usually warm enough for immediate feeding. As a supplement in this case it is necessary to use something that is moderately rich in albuminoids. A protein equivalent of 20, and a starch equivalent of the order of 70, may be taken as

a general guide, and unless fish meal is included, a mineral addition will generally be beneficial. Examples of suitable mixtures are: (1) two parts linseed cake, two parts flaked maize, one part oats, one part fish meal; (2) two parts linseed cake, one part cracked beans, one part middlings, with 1 per cent. each of ground limestone and sterilized steamed bone flour, and ½ per cent. of common salt. It is, however, impossible to make up a whey ration to an energy value equal to that contained in a full allowance of whole milk; the digestive system of the calf is not capable of dealing with so large a quantity of nutrients in the more bulky and less digestible form. An average calf may receive 1½ to 2 gals. of whey with 1½ lb. of the substitute. The rate of growth will generally be about half that obtained with a full ration of whole milk, or about 1 to 1¼ lb. per day, but the daily food cost may be reduced to about one-fourth of that of whole-milk feeding.

On farms where milk is produced for liquid consumption, separated milk and whey are only exceptionally available. Ordinarily, in such cases, only heifer calves from good cows are reared, and economy in the use of milk must be closely studied. With care and good management satisfactory results can be obtained with some 30 or 40 gals. of milk per head, spread over the first seven or eight weeks of the calf's life. This allowance can be reduced to perhaps 25 gals. by the use of a carefully compounded milk substitute (calf starter). The feeding of a milk substitute is commenced at the age of two or three weeks and the allowance of milk begins to be reduced at about the fifth week. The substitute—usually a mixture of ordinary feeding stuffs of low fibre-content—may either be fed dry or made up with hot water into a gruel. The former is less troublesome where the animal can be induced to eat a sufficient amount, but some calves refuse to do so, when it is usually best to resort to gruel feeding. The components of the mixture should be easy of digestion, the starch equivalent being of the order of 75 to 80, and the protein equivalent about 18. A fairly suitable mixture for dry feeding might be three parts flaked maize, two parts finely broken linseed cake, and one part fish meal, though better results are obtained if some separated milk powder is included. For gruel feeding special "milk equivalents" or "calf starters"—composed of dried whey and separated milk, linseed meal, finely ground cereals, etc.—are obtainable. A suitable formula, which

is approved for "National Calf Starter," is thirty parts dried whey powder, fifteen parts dried skim-milk, thirty parts linseed-cake meal, ten parts feeding wheat flour, ten parts oats, two and a half parts dried grass meal, one and three-quarter parts carbonate of lime, and three-quarters part common salt. Hay of good quality should be offered from the age of two weeks. A salt-lick should be provided from the time that the calf begins to take solid food.

The allowance of milk products, or of "milk equivalents" (such as the "calf starter" mentioned above), may be reduced after about three months of age and discontinued at four months old, provided always that first quality hay and ordinary concentrates of high digestibility are available. If the hay is of really choice quality, a concentrate mixture with a starch equivalent of about 65 and a protein equivalent of about 12 will suffice. Suitable mixtures are three parts of oats and one part of linseed cake, or five parts oats and one part decorticated earth-nut cake. Hay should be offered *ad lib.* if the concentrate is readily eaten, otherwise the hay allowance should be such that the racks will be empty for an hour or two before the time for the concentrated feeding.

Consumption of hay may be about 3 to 4 lb. at three months of age and will increase to about 6 lb. at six months. The allowance of concentrate should be of the order of 3½ lb., and need not be increased, since the increasing total requirements are met by the increasing consumption of hay.

Where hay of only average quality is available, the concentrate should be correspondingly richer. Perhaps the best recourse in this case is to continue the feeding of material of the "calf starter" type at the rate of about 1 lb. a day, in substitution for an equal amount of oats or other starchy concentrate. Some farmers prefer to feed the starter as gruel, and to give the other concentrate in dry form.

Finally, it should be said that no attempt should be made to adhere to rigid rules and quantities, since there is considerable variation in the adaptability of individual calves to artificial systems of feeding. Close observation must be maintained and adjustments in diet made according to the progress of the animals. The chief signs of inadequate nutrition are a pot belly, a thin back, and costiveness or laxness of the bowels.

From the age of six months the calf is no longer dependent

upon milk or milk substitutes, but still requires a moderately concentrated ration, excluding such materials as straw, if it is to make full growth.

The following is an example of a winter ration for a Shorthorn calf of six months old, weighing 3 cwt., and intended for beef at two years old. Such an animal kept in good growing condition should make a live-weight increase of rather more than 1¼ lb. per day. Requirements may be calculated as follows:—

	Lb.
1. Dry matter consumption at 2½ per cent. of live weight .	=8·4
2. Energy requirement—	Lb. S.E.
(*a*) Maintenance (see p. 573)	=2·70
(*b*) Production, 1·3 lb. live-weight increase at 1¾ lb. starch equivalent per lb.	=2·28
Total energy requirement .	=4·98
3. Protein requirement (about one-sixth of the total starch equivalent)	Lb. P.E. =0·83

	Composition per cent.			In Ration		
	Dry Matter	Starch Equivalent	Protein Equivalent	Dry Matter	Starch Equivalent	Protein Equivalent
20 lb. swedes . .	11·5	7·0	0·7	2·30	1·40	0·14
3 ,, meadow hay .	85·7	31·0	4·6	2·57	0·93	0·14
1½ ,, oats . .	86·7	60·0	7·6	1·30	0·90	0·11
1 ,, flaked maize .	87·0	84·0	9·2	0·87	0·84	0·09
1 ,, palm-kernel cake	89·0	75·0	17·0	0·89	0·75	0·17
½ ,, white fish meal	87·0	59·0	53·0	0·43	0·28	0·26
Totals .				8·36	5·10	0·91

The age at which hand-reared calves may safely be turned out to pasture varies with the conditions. If the pasture be of good quality and "clean" (*i.e.* free from husk and stomach worms), calves born in February may go to grass in May. Where husk is very prevalent, cattle are generally kept indoors until they are at least nine months old.

In New Zealand very satisfactory results are obtained, in the case of dairy calves, by grazing, without concentrates, from the age of eight to ten weeks. This is done under a modified system of strip grazing, with the calves moving ahead of the other stock.

In summer, calves after the age of six months will do well on ordinary grass with the addition of perhaps 2 lb. of any of the less fibrous concentrates. Cotton cake should not be used till the animals are more than three months old; after this age it may be used in moderation provided that the cattle are amply supplied with calcium and vitamins as contained in pasture or in a combination of good hay with some green food.

The general scheme of feeding varies according to the purpose for which the particular animal is being reared. If intended to be fattened at an early age it must have a liberal ration with preferably a fair quantity of whole milk in the early stages. Weaning should be late, and should be carried out by easy stages in order that the "calf flesh" may not be lost. At the other extreme, a heifer intended for the dairy is purposely kept rather lean, the belief being that otherwise she may develop an undesirable tendency to fatten, and may probably fail to reach her full milking capacity. It is always inadvisable, however, to restrict the ration so much as to check the animal's growth.

As regards housing and general management, young calves should be housed, either singly or in small lots, in well-ventilated but not draughty pens, which should be floored with concrete and swept out and freshly littered daily. They will frequently eat their litter if this be not prevented, and the consumption of straw or peat moss may have fatal results. Calves that develop this tendency may be muzzled for the first three or four weeks, a precaution that also prevents their suckling each other about the navel. In summer they should run on fresh and clean grass, and shade during hot weather is a great advantage; but in many districts it is necessary, as a precaution against "husk" or "hoose," to keep the younger animals indoors during their first summer. This applies to such as have not been weaned at the beginning of the grazing season. When heifer calves are to be vaccinated against contagious abortion, the best age is about seven months. Young cattle at grass should not have access to the contaminated water of open ponds, since such water may be infected with the organisms of Johne's disease. Males should be castrated at about four weeks old.

When the period immediately following weaning has been successfully passed, the feeding and management become simple. In summer, young cattle do well on ordinary pasture without artificial feeding, the only exception being in the case of animals

that are intended to be marketed fat at an early age—say, before they are two years old. The latter should have an allowance of 2 to 4 lb. of concentrate, unless the pasture is more than ordinarily good. Yearling cattle will require from half an acre to an acre or more of pasture each, according to its quality. In winter, growing cattle may be tied up in stalls, or run in covered courts or partially open yards. In districts where the winter is mild—*e.g.* the south-west of England and south-west of Ireland—those of eighteen months or more do best out of doors, if reasonably dry and well-sheltered pastures are available. Store animals will thrive when closely confined, but young animals that are being intensively fed must have exercise if they are to be prevented from "going off their legs." An open court, or failing this, a covered court with a daily run on pasture, is preferable even in the case of stores, as the animals grow better coats and are much less liable to suffer a set-back when they come to be turned out in spring. The following are examples of winter rations:—

1. For a twelve-months-old store bullock weighing 5 cwt., in an arable district:—

	Lb.
Swedes	40
Oat straw	8
Oats and beans, or compound dairy cake	3

This supplies about 14 lb. of dry matter (equal to $2\frac{1}{2}$ per cent. of the live weight), 6·4 lb. starch equivalent, and 0·85 lb. protein equivalent. The maintenance energy requirement is 3·7 lb. starch equivalent, and the surplus, viz. 2·7 lb. starch equivalent, is sufficient for something over 1 lb. live-weight increase per day.

2. For a two-year-old store bullock of 8 cwt., intended for early summer fattening, in a grassland district with a daily run out on pasture:—

	Lb.
Meadow hay	20
Oats, barley, or other cereal	4

This supplies 21 lb. dry matter, 9 lb. starch equivalent, and 1·2 lb. protein equivalent. The maintenance requirement is 5·5 lb. starch equivalent, so that the balance available for production would be 3·5 lb., sufficient for fully $1\frac{1}{2}$ lb. live-weight increase. In actual practice the full ration of hay would be given only for a short period, say from January till March, the quantity being regulated during the remainder of the winter according to the state of the grazing.

MILK PRODUCTION

The first essential to any profitable system of milk production is a herd of deep-milking cows. It is true that the actual yields, as well as the profits, depend very largely on the skill of the dairyman in feeding and general management; but no management, howsoever perfect, can prove successful if the cattle have a low limit of production. Hence everything possible must be done to secure good foundation stock, and, by careful selection and mating, to maintain or improve the average yield. To this end a system of milk recording is essential. Individual cows, under what may be termed ordinary farm conditions, vary in yield from 200 or 300 to 1000 gals.[1] or more, and accordingly may leave a large profit or a very considerable loss. The average yield of the world's dairy cows is probably not over 400 gals., whereas good herds, with a standard of management that is quite attainable under strictly commercial conditions, may reach 800 or 1000 according to breed, and occasionally more. The composition of the milk varies, too, with the breed and with the individual; in particular the percentage of butter-fat, which is the most valuable constituent, may be anything from 3 to 6, without counting very abnormal individuals. There is no adequate evidence as to the hereditary factors that determine production, nor of the mode of their transmission; but we know, in a general way, that milking qualities are inherited, and hence milk records, apart from their value as a measure of the economy of production of individual cows, are of the utmost importance in breeding.

An actual record must always be considered in relation to the conditions under which it is made. Obviously, the size of the cow must be taken into account. The economy of milk production, as has previously been pointed out, depends essentially on the ratio between the production ration and the maintenance ration; the latter varies, not in direct proportion to the live weight but with the three-fourths power of the live weight. Thus, for example, a 12 cwt. cow will require about 35 per cent. more for maintenance than an 8 cwt. animal, and hence it may be calculated that 800 gals. from the latter would be as profitable a yield as 1080 gals. from the former. Clearly, too, a record must be considered in relation to the general system of feeding. An insufficient ration will limit the production and prevent the animal from giving any true account of herself.

[1] A gallon of milk is taken for practical purposes as 10 lb.

Again, age has a well-known influence on yield. From the fourth lactation onwards the cow may be considered as mature, and little increase in yield occurs after this time. Naturally, the yield declines ultimately, but the age at which the decline sets in may vary from eight years to perhaps twelve. A heifer calving for the first time at thirty months old may be expected, in her first lactation, to produce about 75 per cent. of her mature yield, and with her second and third calves about 85 and 90 to 95 per cent. respectively. The butter-fat content of the milk varies but very little with age.

The normal lactation may be taken as lasting about ten and a half months. The cow should have at least six weeks'—and preferably eight weeks'—rest before calving, and should be in calf again three months after freshening. An abnormally long period of rest previous to calving has the effect of increasing the yield during the subsequent lactation, up to a maximum of about 15 per cent. above the normal yield. Conversely, if a cow is not rested at all, her subsequent yield may suffer to the extent of 15 or 20 per cent.

Delay in mating has the effect of permitting a longer continued flow, and a cow that does not conceive at all will ordinarily give about 30 per cent. more milk than one which conceives at the normal period of three months after the previous calving. Under the National Milk Records Scheme (England and Wales), the standard lactation period is 305 days—*i.e.* the lactation yield is taken as the amount produced in 305 days from calving. A long period of rest, particularly if the cow be fattened, may have the further result of increasing the butter-fat content of the milk during the first few weeks of the subsequent lactation.

Finally, the season of calving has an important influence on the yield. The change from winter to summer feeding usually stimulates the flow, whereas the generally poor quality of autumn pasturage has the opposite effect. This effect is greatest if the change occurs at the time when the yield is beginning to decline, say three or four months after calving. It has been found that a cow calving in December may yield 10 to 15 per cent. more than another of equal real capacity calving in June; but, obviously, no generalisation can be true for all conditions, and the more skilful the winter feeding the less will be the effect of season of calving. Thrice-daily milking produces a higher yield than the usual twice milking, and this should also be remembered in interpreting records.

Even when all these factors have been allowed for, an actual record does not necessarily reflect accurately the inherent milking capacity of the cow. The level of nutrition in the herd and the degree of skill brought to bear in its management have very considerable effects on yield.

Many attempts have been made to estimate milking capacity on the basis of short tests—of, say, seven days' duration. It has been shown that with cattle that are fed and managed in the ordinary way there is actually a very high correlation (about 0·85) between the maximum daily yield, at, say, six or eight weeks after calving, and the total yield in a normal lactation. The relationship is, on the average, such that if the maximum daily yield of a winter-calving cow is multiplied by 200, there is obtained a very fair approximation to the normal lactation yield. For summer-calving cows the factor would be about 185. Thus an average cow, producing, say, 3 gals. a day at her best, might be expected, if she calved in winter, to reach 600 gals. in a normal lactation. Since, however, the correlation is not absolute, the rule is not strictly applicable to the poorer milkers or those that are much above the average. The difference from the average should be multiplied by 0·85, the coefficient of correlation, and the product again multiplied by the lactation factor. Thus if we assume that 600 gals. is an average yield, a 5 gal. cow, calving in winter, should produce in a lactation $(3 \times 200) + (2 \times 0{\cdot}85 \times 200) = 940$ gals. Similarly, a winter-calving cow, yielding 2 gals. at the top of her flow, might be expected to produce $(3 \times 200) - (1 \times 0{\cdot}85 \times 200)$, or 430 gals., in a normal lactation.

Short-period tests, in spite of their inherent value, are of very little use in practice. The difficulty is that it is possible, by special feeding, to stimulate the flow for a short period, as well as temporarily to raise the butter-fat content. Even yearly records are open to objection in cases where the cattle are carefully rested and prepared, or where mating is delayed beyond the normal time. The average production over a series of three or four years is by much the best measure of value. Indeed some of the breed Societies now stress the importance of this by setting up the "10,000 gal. cow" as the ideal—*i.e.* a cow which yields an average of 1000 gals. per year over a productive life of ten years.

Milk records, if they are to receive general recognition, must obviously be vouched by an independent authority. In some systems the milk is weighed and tested at regular intervals by the

official recorder, but this method is costly if the visits are frequent enough to give an accurate estimate of the yield. The better system is to make the owner responsible for weighing and recording the yield at each milking, and to have the milking inspected, the weights checked, and the milk tested for butter-fat content by inspectors making surprise visits.

FEEDING FOR MILK

The feeding of dairy cattle, if maximum production is to be made possible and waste prevented, is necessarily a somewhat complicated business. Sufficient energy, protein, minerals, and vitamins must be supplied to provide for maintenance and something approaching the quantity of milk that the cow is capable of yielding. The maintenance requirement is 0·6 lb. of protein equivalent and 6 lb. starch equivalent per 1000 lb. live weight. A gallon (10 lb.) of average milk contains 0·35 lb. of protein, so that the protein requirement, per gallon of milk produced, cannot be under this figure. In fact, good results have been obtained with an allowance of 0·45 lb. per gal., but a somewhat higher rate is probably advantageous in maintaining production during the later stages of lactation. The accepted standard is now 0·55 lb. protein equivalent per gallon of average milk (3·75 per cent. butter-fat).

The total or *gross* energy value of a gallon of average milk (3·7 per cent. butter-fat) is about 3200 Cals. If, therefore, we were to take Kellner's value for the pound of starch equivalent—viz., 1071 Cals. of net energy—it would be necessary to feed 3 lb. ($\frac{3200}{1071}$) of starch equivalent for each gallon of milk produced, for the cow must have enough net energy in her food to produce the gross energy in her milk. The value of 1071 Cals. of net energy per pound of starch applies, however, to fattening oxen, and it has been shown that the milking cow is distinctly more efficient as an energy transformer than the fattening steer. The probable explanation of this fact is that the cow has a direct outlet in her milk for protein and carbohydrate, and is not under the necessity, as is the fattening animal, of transforming its whole surplus energy into the form of fat. The difference in efficiency is considerable, amounting to fully 25 per cent. Expressed differently, the pound of starch equivalent yields 1360 Cals. in the form of milk as against 1071 Cals. in the form of body fat.

The quantity of starch equivalent required per gallon of milk of average composition is thus $\frac{3200}{1360}$, or 2·35 lb. approximately. The energy requirement per gallon will, of course, depend on the composition of the milk, notably on its fat-content. Moreover, cows that are fed in excess of their calculated requirements maintain relatively larger yields, in the later stages of lactation, than those which receive bare theoretical allowances. The optimum level of feeding thus depends on economic conditions, particularly on the relative prices of feeding stuffs and milk. The table below embodies the recommendations which are generally accepted, though some individual authorities regard the figures as somewhat too high for average conditions.[1]

In the case of the cow giving milk of average composition, and where ordinary cakes and meals are to be used as the pro-

Production Standards (per 10 lb.) in respect of Milk in varying Qualities.

Fat-content of Milk (per cent.)	Cals. per Gallon	Starch Equivalent	Protein Equivalent
		Lb.	Lb.
3·5	3170	2·40	0·52
3·75	3250	2·50	0·55
4·0	3430	2·60	0·58
4·25	3510	2·70	0·61
4·50	3600	2·80	0·63
4·75	3680	2·90	0·66
5·25	3820	3·10	0·72

duction ration, the quantity required will be about 3½ lb. per gal. This implies a starch equivalent of 71 per cent. and a protein equivalent of 16 per cent. Such a ration will contain fully 3 lb. of dry matter. As is pointed out in the chapter on nutrition, the cow's food capacity generally lies between 2½ and 3 lb. of dry matter per 100 lb. live weight per day; 3 lb. of dry matter per hundredweight (112 lb.) is a good general figure. Hence if we are dealing with cows of 11 cwt. live weight, with yields running up to 5 gals., maintenance requirements must be met by a ration containing not more than 18 lb. of dry matter (33 lb. total minus 15 required for production). The following are examples of rations supplying the necessary minima of energy and protein (7·1 lb. starch equivalent and 0·71 lb.

[1] See page 577.

protein equivalent) for maintenance in not more than the bulk indicated :—

(*a*) 20 lb. good hay (medium hay is generally given a starch equivalent of 32, very good hay one of 40. A starch equivalent of 35 would meet the case).
(*b*) 40 lb. swedes or mangolds with 14 lb. medium hay.
(*c*) 30 ,, tare-and-oat silage with 10 lb. medium hay.
(*d*) 60 ,, swedes, 6 lb. oat straw, 6 lb. medium hay.

The first is suitable for grassland farms, the second and third for mixed farms; the fourth can be successfully used only in districts where the roots and straw are known to be of at least average quality, for there are many places in which these foods fall short, in nutritive value, of the figures given in the tables. On the other hand, in areas where roots and straw are exceptionally nutritious—*e.g.* in north-east Scotland—the last ration might provide not only for maintenance but also leave some surplus for production.

As regards the production ration, this ordinarily consists of a mixture of three or four distinct materials. The following are suitable standard mixtures to be fed at the rate of 3½ lb. per gal. :—

(*a*) Two parts maize meal, one part crushed oats, one part bean meal, two parts palm-kernel cake, one part decorticated earth-nut cake.
(*b*) Two parts maize gluten feed, one part rice meal, one part barley meal, one part linseed cake, one part decorticated cotton cake.
(*c*) One part coconut cake, one part decorticated earth-nut cake, one part linseed cake, two parts palm-kernel cake, two parts rice meal, one part maize gluten feed.

In the choice of concentrates, apart from questions of price, due regard should be paid to the type of maintenance ration. If this is costive in tendency the production ration should be laxative and *vice versa*. Coconut cake, linseed cake, and decorticated earth-nut cake are laxatives, while cotton cakes, dried grains, and most of the starchy foods have the opposite tendency.

Since 1939 individual " straight " feeding stuffs have been in very irregular supply, and most farmers have made use of compound cakes, and meals.

Dairy compounds are of two broad types—viz. *balanced* and

balancer, the latter for use, in conjunction with home-grown cereals, in specified proportions.

It will be clear that a scheme based on maintenance and production rations such as those indicated above does not meet the case of heavy milkers, viz. of cows of average appetite giving more than 5 gals. per day. While the proportion of cows that actually give 5 gals. or over on winter feeding is small, there is no doubt that many more are inherently capable of doing so. A very partial solution of the difficulty is to increase the concentration of the production ration in such degree that 3 lb. will provide the necessary nutrients for 1 gal. This implies a starch equivalent of 83 and a protein equivalent of 20 per cent. Such a mixture might be composed, for example, of equal parts flaked maize, palm-kernel cake, bean meal, coconut cake, decorticated earth-nut cake, and crushed linseed. But a more satisfactory method is to reduce the bulk of the maintenance ration by substituting concentrates for hay. It has been found that the coarse fodder can be reduced to 8 or 10 lb. without harm to the health of the cow. The maintenance ration may be made up with the lighter type of concentrate, such as a mixture of two parts bran to one part flaked maize. Thus 10 lb. of good hay, 4 lb. bran, and 2 lb. flaked maize would provide the maintenance requirements of a 1200 lb. cow, and leave room for a 7-gal. production ration. The feeding of still heavier milkers becomes something of an art, involving careful study of the taste, appetite, and reactions of the individual animal.

The object of rationing according to yield is, of course, to ensure, without waste of food, something approaching the maximum yield of milk of which the cow is capable, while enabling her to maintain herself in good thriving condition. Cases of individual cows becoming too fat or too lean do frequently occur in rationed herds, generally because due regard is not paid to variation in the composition of the milk. In such cases the ration should be altered at discretion.

An important point in dairy-cow management is that the cow should be brought into fit bodily condition and accustomed to a fairly substantial ration of concentrates before she calves. This process may commence (with 3 or 4 lb. of cake per day) six weeks before the calving date, and the ration may be raised to 8 or 10 lb. for the last fortnight. A mild purgative should be given when it appears that parturition is imminent. Only a light ration should

be fed for the first few days after calving; but thereafter the concentrate should be rapidly increased day by day until it exceeds, by 2 or 3 lb., the allowance corresponding to the actual yield. Excess should continue to be fed so long as the yield shows a tendency to rise, which may be for as long as six or eight weeks. Thereafter the ration should correspond to the actual yield.

The mineral-content of the ration requires special consideration in certain cases. The moderate milker receiving a full maintenance ration will normally get enough mineral matter, at least if the bulky foods have been produced on land that contains sufficient lime and phosphates. The heavy milker, on the other hand, will receive a large proportion of her food in the form of cakes and meals, most of which are deficient in minerals, particularly calcium. The addition to the production ration of 3 per cent. of a mineral mixture will be desirable in such cases. One part powdered chalk, two parts common salt, and one part sterilized steamed bone flour form a mixture which has given satisfactory results. Blocks of mixed minerals, which are obtainable commercially, may, as an alternative, be fixed in the mangers, and the cattle allowed to lick them at will.

The composition of the milk is in the main independent of the feeding, but rations that are low in calcium tend to depress the content of solids other than fat. Chronic undernutrition, produced by the continued use of rations of inadequate energy value, seems to have the same effect. Some materials—such as maize gluten feed, coconut cake, palm-kernel cake, and earth-nut cake—have a slight and sometimes only temporary effect in the direction of increasing the butter-fat content. On the other hand, there is some evidence that rice meal has a depressing effect on the fat-content. The matter is, however, not fully understood. In any case, a high oil-content in the ration is undesirable, and it should not exceed 5 or 6 per cent. The character of the butter-fat is markedly influenced by feeding—linseed cake, for example, produces a soft oily butter, while bean meal, coconut cake, and palm-kernel cake produce a firm fat. The colour of milk, due largely to its content of carotene, is also greatly influenced by feeding, although, as previously pointed out, it varies with the breed and individuality of the cow. Some breeds, notably Guernseys and Jerseys, pass on carotene in their milk, which accordingly has a deep creamy colour. Cows of other breeds, such as the Ayrshire and Friesian, convert a much larger proportion of the food carotene into the

colourless vitamin A. The green leafy portions of plants have a high carotene-content and hence pasture grass, kale, etc., impart to milk a desirable creamy tint. The carotene of grass, etc., is fully preserved by artificial drying or by low-temperature ensilage, but is largely destroyed in the ordinary process of haymaking. The point is of importance, since milk of high carotene-content has a high vitamin A potency. The amount of food carotene or vitamin A required to maintain the full potency of the milk is not large. It can be provided by about 5 lb. of fresh young grass, by 1 lb. of high quality dried grass, or by 2 oz. of cod-liver oil per day.

Regarding the arrangement of the diet, concentrate may suitably be given just before milking. Roots, beet tops, or silage, which, when given shortly before milking, are most liable to taint the milk, should be given not less than three or four hours before milking [1]; long fodder, which is liable to contaminate the air with dust, should be fed soon after milking. The following is an example of a suitable arrangement of the diet:—

5.45 A.M.	One-half concentrate.
6 to 7.15 A.M.	Milking.
7.15 A.M.	Half root ration.
9 A.M.	Half long fodder.
10 A.M.	Outdoor exercise in fine weather.
2 P.M.	Half root ration.
4.45 P.M.	One-half concentrate.
5 to 6.15 P.M.	Milking.
6.30 P.M.	Half long fodder.

The actual times are determined in certain cases by the hours at which the milk has to be delivered.

On the question of the preparation of the food it may be taken as a good general rule that roots should be fed either whole or roughly sliced, coarse fodder in the long state, and the concentrate in dry form. Chaffing may be desirable in the case of animals that waste good fodder. Straw and poor-quality hay are best fed unchaffed, so as to allow the animal to reject the coarsest and least nutritious portions. For production purposes a mixture of cake (in nut form) with meal is better than meal alone. The feeding of wet mash is common in certain districts, but it is a method of very doubtful economy—except, of course, where wet beet pulp or brewers' wet grains are used.

[1] Where the cattle spend an hour or two at pasture, such foodstuffs are best fed out of doors; this avoids the risk that the taint will be picked up from the atmosphere of the cow-shed.

A supply of pure drinking water is necessary for cattle in milk, unless the ration contains both an excessive quantity of roots and a considerable amount of water in the form of mash. The normal consumption of a cow yielding 2 gals. of milk per day, fed on a dry ration, and in ordinarily cool weather, may be put at 10 gals. daily. Heavy milkers, in hot weather, have been observed to consume up to 25 gals. The most satisfactory method of supplying water, when the cattle are indoors, is by means of automatic drinking bowls. Failing these, water should be offered thrice daily, the last drink being given as late in the evening as is practicable.

In summer, if cattle are on fairly good fresh pasture, it will generally suffice to give 3½ lb. of concentrate for each gallon of milk produced above 2 gals.; or, in case of average pasture during the earlier part of the season, for each gallon above 3 gals. The best grazings, for a few weeks during May and June, can support production up to 5 gals. per day. When pastures get bare, much additional food may require to be given, such as cut green forage, mangolds in early summer or cabbages later, hay, and additional concentrate. Even if grass is abundant its feeding value generally declines from August onwards, and during October it will do little more than provide for maintenance. Deep-milking cows on rough autumn pastures should have their grazing restricted, since otherwise they may consume too much of the bulky and innutritious herbage. An average cow requires from 1 to 1¾ acres of pasture, according to its quality, when this is managed on the ordinary system, or about ¾ acre under a highly intensive system of management.

Pastures that contain an excessive proportion of legumes—*e.g.* white clover or lucerne—are liable to cause bloat. Young cattle, fattening cattle, and sheep are liable to the trouble, but it tends to be most severe in the case of cows in full milk. In some cases the feeding of hay or other roughage before the cattle go to pasture is an effective preventive.

Where soiling is practised, the ration of green forage may be from 60 to 80 lb., according to its feeding value and the size of the cow, with the usual allowance of concentrate. High-quality material may be fed in larger amounts, and the concentrate reduced in amount or omitted.

It is worth noting that many summer foods, such as clover, vetches, and ordinary pasture grass, are much richer in protein than most home-grown winter foods, such as roots and hay.

Hence the concentrate fed in summer may frequently be so made up as to have a nutritive ratio of the order of about 1 : 6 or 7 and yet give fully satisfactory results. This may permit the use of a mixture of, say, sharps, maize meal, and palm-kernel cake, which will often be appreciably cheaper than the type of mixture described on page 633.

In all cases feeding should be at strictly regular hours. The cattle should be quietly handled, should be groomed daily during winter, and should have some little outdoor exercise, except when icy roads might lead to accidents, or when the weather is exceptionally inclement. The hoofs may require occasional dressing to prevent their growing too long.

HOUSING AND HYGIENE

Cow-sheds should have ample air space. Some local authorities prescribe 600 cub. ft. per cow, or 800 if the cattle are continuously indoors. Much more important than the actual cubic space are efficient ventilation, good lighting and drainage, and facility for cleaning. The floor should be of non-absorbent material, such as concrete, except, perhaps, the front part of the stall, which may be of rammed clay or chalk, in order to prevent injury to the cows' knees. Rubber bricks and composite bituminous materials are now being used with the same object. The size of the stalls must be adapted to that of the cows; for moderately small breeds, such as the Ayrshire, the double stall should be about 6 ft. 6 in. wide and about 5 ft. 3 in. long, exclusive of the trough. For average Shorthorns an extra 6 in. each way will be necessary. If yokes are used instead of chains the stalls should be made 6 in. shorter, as cows in yokes stand farther forward. Too much width or length is just as unsatisfactory as too little. In the first case a cow is liable to turn partly round in the stall, and to tread on her neighbour, as well as to soil the litter. The depth of the manure channel should be 10 in. behind the cow and about 4 in. next the passage. A suitable general arrangement of a cow-house, with dimensions, is shown in Fig. 34.

The atmosphere of the shed should be kept cool and fresh. It has been shown that there is no gain in milk by keeping the cows at a temperature above 45° to 50° F., and a high temperature has been shown, in some cases, to depress the butter-fat content of the milk. Even in the coldest weather ordinarily experienced

in Britain, free ventilation is unlikely to reduce the temperature to any harmful extent. At the cooler temperature the cattle are much less liable to chills, and are more weather-hardy when they come to be turned out in spring. An adequate supply of fresh air to each cow may be assured by inserting glazed stone-ware pipes in the cow-shed wall, one opposite each standing, at about the level of the top of the manger. The cattle should be kept littered with clean straw, and the floor should be washed as well as swept daily. The lower part of the walls, which should be smoothly

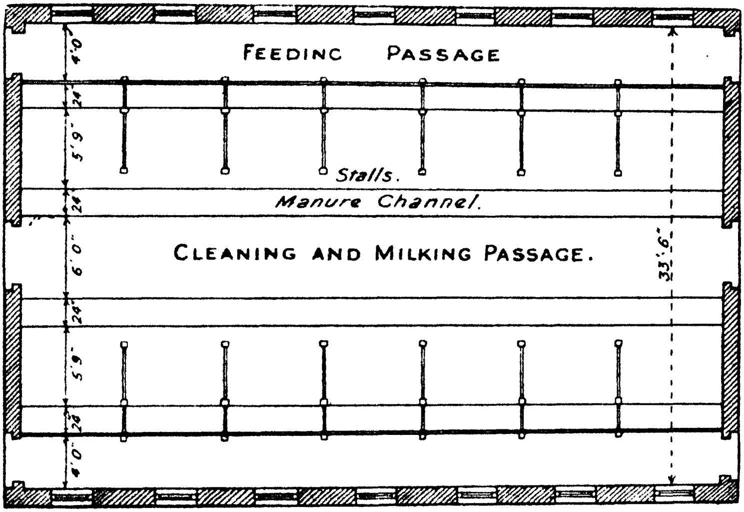


FIG. 34.—Plan of Double Shed for 28 Cows. Dimensions are for cows of average size. Stalls are 7 ft. wide

faced with cement or other material, should frequently be brushed down with water.

The purity of milk, which determines its keeping quality, is judged by its bacterial count and its content of coliform organisms per millilitre, or alternatively by its effect on such reagents as methylene blue or resazurin. These tests depend upon the fact that active bacteria use up oxygen, and that the reagent changes colour on reduction. Milk withdrawn from a healthy udder contains very few bacteria but tends to become contaminated from such sources as unsterilized utensils, the body of the cow, the hands of the milker, dust, etc. As milk is a very suitable medium for bacterial growth the count tends steadily to increase. The rate at which the organisms multiply is most rapid about blood heat

but is less at lower temperatures, and goes on comparatively slowly if the milk is cooled to 50° F. Milk from unhealthy cows may be contaminated by pathogenic bacteria within the udder. Milk infected with the various organisms that cause mastitis is, naturally, capable of infecting other cows but is generally innocuous to humans; milk containing the organisms of tuberculosis is highly dangerous to both humans and bovines.

The following precautions should be taken to ensure clean milk production:—

1. The hind quarters of the cows should be kept clipped and the animals should be groomed daily, but grooming must not take place immediately before milking as this causes contamination by dust during milking. The udder and teats should be washed before milking, but care must be taken that the cloths used for this purpose do not carry infections such as mastitis from one cow to another. To sterilize the cloths, hypochlorite solution may be used according to the instructions of the makers. Where this is done, it is recommended that two pails of solution should be prepared and two cloths added to each. The first pail is for washing down, the cloths being used alternately so that one is in the solution for disinfection while the other is being employed on the cow. The cloths in the second pail are used, time about, for giving a final wipe-down. The first "draw" of milk, which contains a good many bacteria from about the teat orifice, should be rejected.
2. The atmosphere of the cow-shed should be kept free from dust. Dust may come in from outdoors or may be produced by handling long fodder or litter before milking. As it is impossible to exclude bacteria from the atmosphere altogether, a hooded pail should be used (where milking is done by hand) in order that a minimum surface of milk may be exposed. Milk should be removed from the cow-shed as each cow is milked.
3. Personal cleanliness should be required of the milkers, and washing facilities should be provided. The hands may be dipped in hypochlorite solution before and after milking each cow. Wet milking should be forbidden. People suffering from infectious disease, sore throat, sores, or diarrhœa, must not be allowed to handle milk.

Milking Stalls with Releaser Milking Machine

4. All utensils, such as milking pails, etc., should be thoroughly cleansed and sterilized before milking begins. After washing in cold or tepid water, scrubbing in hot detergent solution, and rinsing with hot water, the utensils are placed in the steam-chest and, after sterilizing with live steam for ten minutes after the chest thermometer shows a temperature of 210° F., are left until next required.
5. The milk should be passed through a suitable strainer and immediately cooled, in a clean atmosphere, to as low a temperature as the available water supply will permit or, where refrigeration is available, to below 50° F.
6. Careful watch should be maintained over the health of the cattle, and the milk of any unhealthy animal should be excluded from the general supply. It may, after scalding, be fed to pigs.
7. In order to prevent the spread of mastitis, which is a frequent cause of heavy losses, the milk from each cow may be subjected to bacteriological examination. Where this has been done, all the "clean" cows should be milked before the workers pass to the affected cattle. Still better, each section of the herd may have its own group of milkers. The incidence of the disease is highest in the older animals, so, when the condition of the udders is unknown, it is sound practice to milk the old cows last and the heifers first. As mentioned above, it is also helpful to sterilize the udder cloths and dip the hands in water containing hypochlorite.[1] In the case of machine milking, after each cow the vacuum should be turned off and the cluster of teat cups rinsed in clean cold water, drained for a few seconds, and then dipped in hypochlorite solution. After a final shake the vacuum may be turned on and the machine used on the next cow.

Some authorities are chary in recommending the employment of disinfectants because unreliable workers may make up excessively strong solutions and do harm, or continue to use the hypochlorite solution after its activity is exhausted. Where there is reason to anticipate mishandling of disinfectants it may be better to wash the udders, etc., in clean water and to change the latter very frequently.

[1] There is some hope that some more completely effective means of hand disinfection may be found.

It will be obvious that these general rules may be interpreted in various ways. Where the milk is sold as "ordinary" milk, the price obtained will rarely be sufficient to compensate the producer for the installation of elaborate sterilizing and refrigerating plant, or for all the labour that is required to ensure the minimum of contamination. On the other hand, where the highest class of graded milk is aimed at, no detail can be neglected.

The system of open-air dairying, first devised by Mr A. J. Hosier in Wiltshire, is now fairly common on well-drained grasslands in the South. The cows live out of doors all the year round, and are milked in a "bail," which is a movable set of milking stalls with milking machine and cooler built into the structure. The cows receive their concentrate ration while they are being milked and return to the field immediately milking is finished. The system is very economical in labour, two men sufficing for a herd of sixty or seventy cows. The cattle generally maintain excellent health, though the milk yields are probably a little below those of similar animals managed in the usual way.

Another method of management is to keep the cows either in an ordinary cow-shed or loose in yards (when horns should be cut), and at milking time to drive them into a shed with special stalls, where they are first washed and then milked. A suitable arrangement is illustrated in Fig. 35. A parlour with side-by-side milking stalls and a releaser type milking machine is shown in Plate XLIV.

Such "milking parlours" are being installed in increasing numbers of dairy farms. The cost of fitting out a parlour is much less than that of building a good cow-shed, and existing buildings can often be cheaply adapted as cow-yards. Labour costs are lower and the manure, being made in yards, is much better conserved. The chief difficulty is in rationing the cows, since the period spent in the milking stall is insufficient to enable a heavy milker to consume the appropriate production ration. Many modern yards are, however, equipped with yoked mangers which permit of individual rationing.

MILKING AND FARM DAIRY EQUIPMENT

Four sorts of equipment are needed in the routine operations of milking and milk-handling, whether milking takes place in the cow-shed or in a milking parlour. These are: (*a*) Udder

washing equipment and a strip cup; (*b*) a milking machine or hand-milking pails, and cans into which the milk is finally placed to await despatch from the farm; (*c*) strainers and coolers which are used to minimize bacterial growth in the milk; and (*d*) washing and sterilizing equipment for keeping the utensils

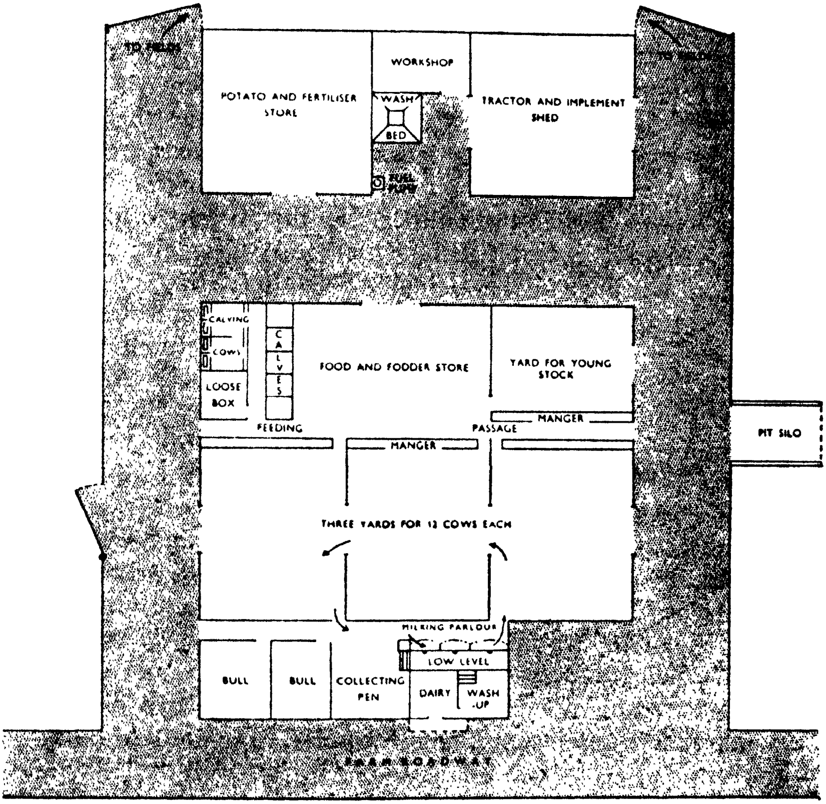


FIG. 35.—Arrangement of Yards and Tandem Milking Parlour for Herd of 40 Cows

in a satisfactory hygienic condition. A special room, the dairy, where all operations except the actual milking are carried out, is required as an adjunct to the cow-shed or milking parlour.

Milking Machines.—All milking machines work on the same general principles and aim to remove milk from the udder as quickly and completely as possible without injury to the animal. Little exact information is available regarding the

effects of specific design features on any of these objectives. The milking action of machines results from a constant vacuum (of about 15 in. of mercury) applied to the inside of a rubber sleeve enveloping the cow's teat, possibly aided to some extent by an alternating pressure applied to the outside of the sleeve or liner. The liner is contained in a metal teat-cup and makes a vacuum-tight seal to it top and bottom. By connecting the space between the liner and cup alternately to the atmosphere and to the same source of vacuum as operates inside the liner, the liner is made to squeeze and release the teat alternately. During the squeeze phase of the cycle, milk flow from the teat ceases as the liner collapses and the teat is protected from the full force of the continuous vacuum applied to the liner. In the absence of pulsation engorgement of the teat occurs with consequent discomfort to the cow and injury to the tissue. The alternating pressure is controlled, at about 50 cycles per minute, by a pulsator which is often a simple valve mechanism operated by a vacuum motor similar in construction to that of a windscreen-wiper. A vacuum pump, driven either by an electric motor or by an internal-combustion engine, is an essential part of the machine.

In the releaser type of installation the milk from several teat-cup clusters is conducted by rubber milk tubes into a metal pipe, the milk-line, fixed at about head height to the standings. The milk-line conveys the milk to the dairy, where it is brought to atmospheric pressure (from the reduced pressure prevailing in the milk tubes and milk-line) by means of a device known as a releaser. The vacuum-line usually runs parallel to the milk-line and pulsators are fitted at each cow standing. In the more elaborate recorder-releaser plants the milk from individual cows is first intercepted by a counterbalanced glass weighing jar and, after milking is finished, the weight of the cow's milk as indicated by the spring balance is noted. Then, by operating a master valve, the milk is drawn from the jar into the milk-line.

While releaser plants are commonly employed in milking parlours, bucket milking plants are normally used for machine milking in cow-sheds. Vacuum cocks at each standing are linked by the vacuum-line to a motor-driven pump, and the portable milking units are connected in turn to the cocks. Each unit consists of a teat-cup cluster connected by rubber milk and vacuum tubes to a special bucket with a vacuum-tight lid. The lid also carries the pulsator and a rubber tube leading to the

vacuum cock at the head of the standing. Milk from the teat-cups is intercepted in the bucket, which is emptied after each cow is milked.

Of recent years " in-can " milking has been introduced, the milk from each teat-cup assembly being received direct into a can (" churn "). For use in cow-sheds the apparatus may be mounted on a trolley or suspended from a monorail running the length of the shed. Stall cocks may be retained or a vacuum pump may be carried with the rest of the equipment. The system is readily applied to open bails and milking parlours. In all cases the can is suspended from a balance so that the yield from each animal may be determined.

With all types of milking machine the rate of milking increases with greater reduction in pressure, but a vacuum greater than 15 in. of mercury is generally considered liable to result in injury to the animal. It is therefore essential that all machines be fitted with accurate vacuum controllers and gauges, and that these components be maintained in perfect condition. The permanent vacuum line should be fitted near the pump with an interceptor trap for collecting condensate and milk in the case of a split liner, and also to facilitate occasional washing. To prevent regurgitation the vacuum line should be laid with a fall and fitted with drain cocks at low points, and, in addition, the vacuum cocks should enter the line at the top.

Milk Strainers.—These are usually fitted to the vessel which receives the milk as it enters the dairy. The body of the strainer is fitted with a perforated holder which supports an easily replaceable filter disc, usually composed of cotton wool mounted between layers of fabric, which is discarded after a single milking. Since all milk is filtered immediately before bottling, and there is no evidence that straining on the farm results in improved keeping properties, the practice of straining seems to serve no other purpose than deceiving the dairyman into thinking that the milk has been produced under cleaner conditions than in fact it has.

Milk Coolers.—Corrugated surface coolers using water as the cooling medium are extensively used for cooling milk on the farm. The method is simple and cheap but in future, as more emphasis is placed on cooling, it is likely that many installations will be found to lack a sufficiently cold water-supply. Deep bores and wells may be relied on to yield water at temperatures

ranging from 50° to 55° F. at all times of the year, and such supplies enable milk to be cooled to 60° F. or lower provided always that the water is pumped direct from the well to the cooler and not allowed to become warm in a tank. Many piped-water supplies are, however, much above 60° F. in summer, and it has often happened in the past that little foresight or ingenuity has been exercised in arranging for the coolest possible water supply for milk-cooling.

Mechanical refrigerating equipment is sometimes used in spite of the heavy capital outlay and the relatively high maintenance and running costs that are involved. The chief application of refrigeration for milk-cooling would seem to be where nothing can be done to obtain an adequate water supply. With such equipment surface coolers may be operated with chilled water, or less satisfactorily with brine or by direct expansion of the refrigerant. It is probably better to dispense altogether with the surface cooler with its attendant problems of cleaning and sterilizing and use the outside of the can as the heat-transfer surface. This may be done by dumping the cans into an insulated tank containing chilled water. The difficulty of lifting the cans of milk may be avoided by spraying the chilled water on to their outsides.

Steam and Hot Water Supply.—Although chemical sterilization with hypochlorite solution may be successfully applied to farm dairy equipment, steam sterilization is at present usually considered the method of choice. A supply of hot water for washing is generally provided from the steam raiser, which may be fired with solid or liquid fuel, or may be heated by electricity. The quantity of steam required varies greatly according to the layout of equipment and the care with which the steam is used, but an evaporative capacity of 20 to 50 lb. per hour should be sufficient for medium-sized installations using milking machines.

Since farm boilers are used only intermittently, and because of the large amount of heat left in the boiler and contents at the end of the operation, their efficiency is low. Electric steam raisers may successfully compete with the oil- and coal-fired boilers because their steady heat input allows of the use of smaller water volumes and consequently of lighter shells. Electric equipment is also clean in operation and may, with very little difficulty, be made fully automatic.

Sterilizing Chests.—Some form of enclosed space for holding

utensils during steaming is required. This may take the form of a sheet-metal chest or small sterilizing room. (All sterilizing chests must be equipped with thermometers.) Where electricity is available, self-contained electric sterilizing chests are popular, and a chest, equipped with a cast-iron heat-storage block, heated with a small electric element, is available. It has the advantage that steam is available at a moment's notice. A suitable arrangement of a milk room designed for bucket or hand milking and

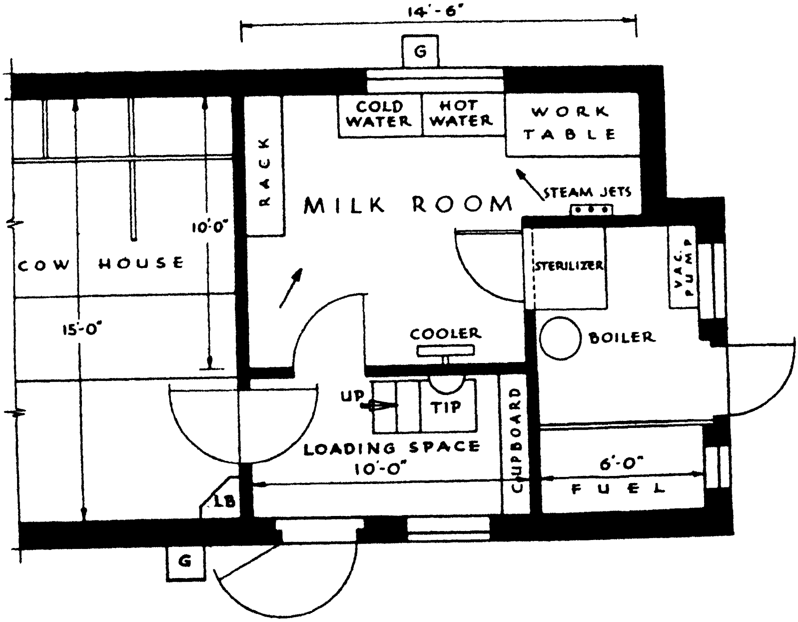


FIG. 36.—Arrangement of Milk Room

using a surface cooler and steam sterilization is illustrated in Fig. 36.

Wet Storage.—One of the most troublesome pieces of equipment to clean and sterilize is the milking machine teat-cup cluster. Racks are available to hold the teat-cups with the open end upwards and the milk tube at the same level. The whole of the interior of the assembly may then be filled with a cleaning and sterilizing solution. The method originated in the U.S.A. where 0·5 per cent. caustic soda was found satisfactory. Not all makes of machine have clusters that are completely liquid-tight.

MILK SECRETION AND MILKING

In the first-calf heifer, and also in the cow which has had a normal dry period, milk secretion begins some time before parturition. In some cases the udder becomes congested and painful several days before calving takes place, in which case it is customary to withdraw some colostrum. If, however, this is done repeatedly over a period of a week or more, the calf will be deprived of colostrum which, as mentioned earlier (see p. 616), is important in relation to the calf's resistance to infection.

In the lactating animal milk secretion goes on continuously, causing a build-up of pressure in the udder. Pressure increases steadily for about nine hours, and afterwards at a diminishing rate. If the milk is not withdrawn, secretion is inhibited and milk is reabsorbed. The milk as it is secreted collects first in the alveoli and the minute ducts leading from them, and later in the milk cistern and teat sinus. At this stage the greater part of the udder might be likened to a milk-saturated sponge, with most of the liquid so tightly held that it will not drain by gravity alone; indeed, a tube passed through the milk orifice will drain only the large sinuses. Some milk may be squeezed out of the secreting cavities and tubules by massaging the udder.

Under natural conditions the nuzzling of the bag by the calf stimulates the cow's pituitary gland to release the hormone oxytocin. This is carried to the udder by the blood stream and causes contraction of the alveoli and ducts so that the cow "lets down" her milk. The effect of the hormone is transitory, and after a period of some seven or eight minutes the milk pressure relaxes so much that even the strong suction exerted by the calf cannot draw the milk from the fine vesicles. Some time must elapse before a fresh stimulus can reproduce the reaction. With the more primitive breeds of cattle the presence of the calf is necessary to produce the response described above, but most cows of the improved dairy breeds, after a few days' experience of hand or machine milking, "let down" completely in response to the handling of the teats and even to a gentle touch on the udder. There are, however, considerable individual differences between "easy" and "hard" milkers. These differences depend in part on the size of the teat orifice. Some cows can be milked out by machine in three or four minutes, whereas others require as long as eight. Moreover, excitement, fear, or pain causes the

secretion of adrenalin into the blood stream and this counteracts the effect of the oxytocin. This explains the importance of quiet and gentle handling of cows at milking time.

The pressure of milk in the udder reaches its maximum about one minute after the appropriate stimulus has been applied; so that the timing of the commencement of milking is important. Moreover, since the response lasts for a relatively short period, milking should be done quickly.

The massaging of the udder with a hot moist cloth has been advocated as the best "signal" that milking is about to commence, but it does not seem that this particular process is necessary. Many cows react to other stimuli, including even the noise produced by handling the milking equipment. The important matter seems to be to follow an accurately timed routine of operations up to the point when milking is begun, and to start the operation about a minute after "let down" has been induced.

In hand milking, the teat is first grasped at its junction with the udder, between the forefinger and thumb, so as to prevent the milk from being pushed back into the milk cistern; pressure on the teat is then extended downwards by closing the other fingers, in succession, against the palm, so that the milk is driven out through the teat canal. In the final operation of "stripping," the forefinger and thumb are drawn from the base of the teat downwards along its whole length.

The action of the milking machine, which is different in that both suction and pressure are employed, has already been described (see pp. 643-945). The chief point in machine milking is to prevent the teat cups crawling upwards towards the end of the operation. As the milk is withdrawn the udder tissue becomes flaccid and the suction has the effect of drawing the cups upwards until they may press upon and damage the delicate membrane between the milk cistern and the teat, which should open when suction is applied, allowing the milk to flow freely from the milk cistern into the teat. This difficulty was formerly met by removing the machine before milking was complete and by subsequent hand stripping; but equally good results can be obtained by the machine if the appropriate technique is employed. This is to pull gently on the cups with one hand while massaging the bag with the other. In any case it is very harmful to leave the teat cups on the teats after the udder is empty; damage caused to the tissues

through this malpractice is an important predisposing cause of mastitis.

Where a regular milking "drill" is constantly observed for a period, a majority of cows can be milked out in a period of three to five minutes. A considerable economy of time is to be gained by grouping the slow milkers together in the shed.

Milking need not be done more than twice a day, except in cases of heavy milkers. A change from three milkings to two will generally produce a diminution of the yield, but the 2- or 3-gallon cow soon adapts herself to the new routine. Heavy milkers have been found to yield from 10 to 20 per cent. more milk when milked thrice daily. The intervals between milking should be as nearly equal as possible, because otherwise the butter-fat content of the milk, after the longer period, will always be low. With milkings at 6 A.M. and 3 P.M., a somewhat common arrangement, it has been shown that the morning milk may be quite 0·5 per cent. lower in butter-fat than the evening milk, and hence may sometimes fall below the legal minimum standard of 3 per cent. Milking should be done quickly and thoroughly. A good hand milker may be expected to milk from seven to ten average cows in an hour and a half, the time ordinarily allotted for the work.

Cows that are still milking at six weeks before their next calving time should then be put dry. It will often suffice merely to stop milking, when secretion will cease and the milk will be reabsorbed. Sometimes partial withdrawal of the milk is necessary, but this should be avoided unless the animal is in pain.

BEEF PRODUCTION

The type of animal best suited to the production of beef has been sufficiently described in the last chapter. There can be no question that the breeder, if beef is his sole object, should aim at the best possible beef type. But the feeder, if he is nothing but a feeder, may find that the finest commercial type of "store" commands a more or less fancy price, and that he can obtain a larger profit from a somewhat rougher animal that can be bought cheaper. The value of a young calf, as material for beef production, depends largely on its breeding. Indications of beef "blood"—a white face or a black or blue-grey body colour—are generally a better indication of beef value than size or

conformation. Animals with indications of dairy breeding—Channel Island or Ayrshire colours and markings—will rarely make profitable beef animals even if they appear to have good conformation.

Calves at six to twelve months of age should show evidence of reasonably good nutrition since inadequate feeding in calfhood usually does permanent harm. Signs of former starvation are small size, a long narrow face, a thin back, and a pot belly.

On the other hand, " hard wintering " of older cattle does little permanent harm. In particular, cattle that have been out-wintered and fed rather poorly commonly make much better live-weight gains, on grass, than such as have been housed and well fed. The latter often lose weight on the spring grass.

The slaughter age to be aimed at depends on breed. The hardy mountain breeds do not respond to forcing, and the dual-purpose types require more time than the early maturing beef breeds.

Angus, Herefords, and Shorthorns of beef type, if they are well fed as calves, and if they are carried on without a "store" period, can be marketed either as " baby beef " at fifteen to eighteen months or as young beef at eighteen to twenty-four months. This system is well adapted to the better sort of mixed farms where breeding and feeding are combined. On the other hand, feeders who buy in stores and who work on a system of rapid turnover prefer cattle of some age because they fatten more quickly. Two and a half years is about the average age for cattle to be put up to feed, and some of the later-maturing breeds are kept till they are three years old or over. Old and heavy cattle, however, sell in a free market at a considerable discount as compared with young, well-finished animals. Under the system of payment according to grade, which operated from 1939 till 1954, the price per hundredweight was based mainly on the estimated dressing percentage, and the premium formerly commanded by light-weight young cattle was considerably reduced. With the restoration of free markets in 1954, a considerable premium for cattle of moderate size and good quality has again become established.

The general scheme of feeding must be adapted to the prevailing economic conditions. If the fattening process is likely, in itself, to be a profitable operation—*i.e.* if there is any considerable margin between the value per hundredweight of lean and fat animals,

and if feeding stuffs are cheap—the general rule will apply that the more rapid the process of fattening the higher will be the profit. Obviously, if one animal is fattened in four months and another, on a lighter ration, to the same degree in six, the latter is debited with the cost of an additional two months' maintenance, without any compensating advantage. In the past half-century, however, the conditions stipulated have rarely existed, and the winter fattening of cattle has come to be regarded as essentially a means for the disposal and conversion into manure of the bulky and non-marketable by-products of the arable or mixed farm. Hence it has usually been good policy to feed a maximum of such by-products, and to confine the use of purchased concentrates to the barest minimum. Generally, some such concentrates will be necessary if the animal is to obtain sufficient nutrients to enable it to make reasonable progress, and also, in some cases, to correct the protein deficiency of roots and straw.

As regards winter feeding, the ration will depend mainly on the particular home-grown feeding stuffs that are available. On arable farms in Scotland the chief constituents will generally be roots and straw, with a moderate allowance of seeds hay in the latter part of the fattening period. In the eastern counties of England hay is the usual fodder, and sugar-beet by-products largely replace roots. Silage is a good substitute for roots and hay where roots cannot be grown economically. Good silage, made from any of the ordinary mixtures of, say, oats, beans, peas, and vetches, has nearly twice the energy value, weight for weight, of swedes, and more than twice the protein equivalent, so that expensive, highly nitrogenous concentrates become unnecessary. On the other hand, its fibre-content is considerably higher, so that its use leads to a reduction in the amount of straw, etc., that the animal will consume. In semi-arable districts meadow hay will generally be available in quantity and, in pastoral regions, it may form the basis of the ration. In the colder and later arable districts, where grain is often of poor market quality, oats and barley are largely used.

During the progress of fattening, as the animal's appetite for bulky food declines, the allowance of concentrated food must be increased. Wood's standard for a fattening steer allows 12 lb. of starch equivalent and $1\frac{1}{2}$ lb. of protein equivalent per 1000 lb. live weight. On such a ration a 1000-lb. animal should add nearly 2 lb. daily to its live weight, more in the earlier stages

when the live-weight increase consists partly of water and protein, less in the latter when the gain is chiefly fat. Good cattle will readily make such an average increase, as between ordinary store and ordinary fat condition. On more highly concentrated rations $2\frac{1}{4}$ to $2\frac{1}{2}$ lb. per day may be obtained. In practice, as has just been indicated, it may often be wise to rest content with a daily increase of $1\frac{1}{2}$ to 2 lb. using a less nutritious ration. In countries where cheap concentrates are available (*e.g.* maize in the corn belts of North and South America) rations with as high a starch equivalent as 18 or 20 lb. are sometimes fed, and the gain may reach 3 or even $3\frac{1}{2}$ lb. per day for short fattening periods. Such rations are often imperfectly digested, and pigs must be kept with the cattle to consume the residue.

The following are examples of winter rations for arable and semi-arable conditions, and for the beginning, middle, and end of the fattening period respectively. The cattle are assumed to weigh $8\frac{1}{2}$ cwt. at the beginning, and to make an average live-weight increase of 2 lb. per day over a feeding period of five months. The fat weight would thus be about 11 cwt.

Arable Conditions

Beginning	Lb.	Middle	Lb.	End	Lb.
Turnips or sugar-beet		Swedes[1]	70·0	Swedes	60·0
tops	80·0	Oat straw	12·0	Oat straw	6·0
Oat straw	14·0	Palm-kernel cake	2·0	Seeds hay	6·0
Palm-kernel cake	4·0	Linseed cake	2·0	Linseed cake	3·0
Oats	2·5	Maize meal	3·0	Barley meal	5·0
Dry matter	24·0	Dry matter	24·0	Dry matter	25·0
Starch equivalent	11·0	Starch equivalent	12·5	Starch equivalent	13·5
Protein equivalent	1·4	Protein equivalent	1·6	Protein equivalent	1·8

Semi-arable Conditions

Beginning	Lb.	Middle	Lb.	End	Lb.
Turnips	42·0	Swedes	42·0	Mangolds	42·0
Oat straw	6·0	Meadow hay	16·0	Meadow hay	14·0
Meadow hay	14·0	Barley meal	4·0	Barley meal	6·0
Barley meal	3·0	Palm-kernel cake	3·0	Linseed cake	3·0
Palm-kernel cake	2·0				
Dry matter	25·0	Dry matter	25·0	Dry matter	25·0
Starch equivalent	11·0	Starch equivalent	13·0	Starch equivalent	13·5
Protein equivalent	1·4	Protein equivalent	1·7	Protein equivalent	1·8

Much thought was being given, at the time of writing, to reduce the costs of winter feeding. Many cost accounts, drawn up on conventional methods, have indicated negligible profits or

[1] Swedes or mangolds may be largely replaced by dried sugar-beet pulp.

actual losses; but it should be noted that the value of dung, under certain conditions, is in fact much higher than that allotted on the basis of the residual manurial values of the food and litter. This is especially true on the lighter sorts of land where high-value crops, such as potatoes and many vegetables, are grown.

The high costs arise mainly from the high charge of labour requirements of growing fodder roots, of tending housed cattle, and of carting and spreading the manure.

One approach is to shorten the period of house feeding by running the cattle on foggage, beet tops, and kale after the end of the normal grazing season; another is to use silage for a substantial part of the ration; satisfactory results have been obtained on rations composed mainly of silage and cereal foods.

"Baby beeves"—*i.e.* such as are being fattened while still in rapid growth—require a more concentrated type of ration. Straw cannot be successfully used and even hay must be so limited that not more than a third of the dry matter is supplied in this form. In all cases the choice of particular concentrates should be determined by ruling market prices.

Apart from questions of bulk, energy value, and protein-content, the palatableness of the ration may require special consideration. Some feeding stuffs, such as palm-kernel cake, are not readily eaten at first but are consumed freely enough when the animals have had a week or two to become accustomed to them. An occasional animal will refuse any and every sort of cake. Sprinkling with molasses water, or admixture with any of the commercial condiments, will often be helpful. Again, stores from grassland districts take some time to learn to break roots, and an occasional animal gives up the problem altogether. If it is inconvenient to slice the roots for the whole group, such individuals should be transferred, if possible, to individual boxes and given special feeding. Regarding the preparation of the food generally, roots must be sliced for cattle that are in process of changing the first pair of incisor teeth (say eighteen to twenty-four months old). Otherwise it is doubtful whether any special preparation of the food is profitable. Many experienced feeders give the roots whole, the fodder long, and the cake in the ordinary form of nuts or cubes. On the other hand, some feeders chaff a proportion of the fodder, slice the roots, and mix the two together, with or without the addition of meal. This doubtless decreases the work of mastication and enables the animal more

quickly to finish its meal and return to rest, but it involves a large amount of additional labour, and there is no satisfactory evidence that the advantage is sufficient to leave a profit. Only if straw is not being consumed in the quantity desired, owing, for example, to its tough and dry condition, it may be chaffed and either mixed with pulped roots or moistened, and left for a day to ferment slightly before being fed. The concentrate should not be added to the mixture in such cases, as the fermentation causes loss of nutrients without any compensating advantage. Heavy root rations are always liable to cause scouring, particularly in early autumn; materials like soya bean, earth-nut, and linseed cakes, which have also a laxative tendency, should not be fed with them; undecorticated cotton cake, on the other hand, is an excellent corrective.

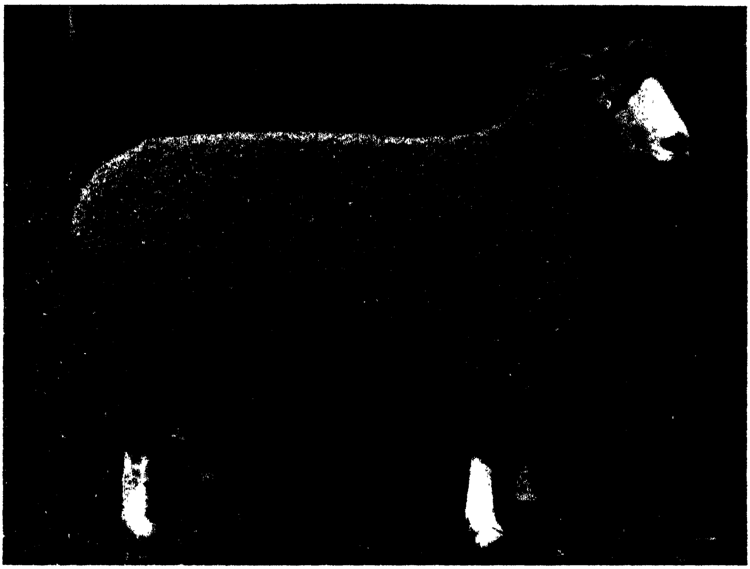
The particular details in the arrangement of the ration are of less consequence than strict adherence to whatever scheme is adopted. In practice straw is generally given *ad libitum*, and the racks are filled morning and evening, or oftener if necessary. The roots should be given in two feeds or, if the ration is over 80 lb., in three; the concentrate should also be given in two meals if the amount exceeds 4 or 5 lb. Many feeders believe in allowing a period of two or three hours of entire quietness in the middle of the day. Cattle receiving very large rations of roots will not require drinking water, but, ordinarily, water should be laid on to the yards. The total consumption of water (including any in the food) is generally about 1 gal. per cwt. live weight per day, or approximately four times the weight of the dry matter eaten.

Regarding housing, fatting cattle may be kept in single or double boxes, or may be run in lots of up to twelve or twenty in covered or partially open yards; or, again, they may be tied up in stalls, as are dairy cows (a common practice in the north). Single boxes doubtless give the best results, but the method is expensive both in labour and in housing space. Stalls are economical of space, 50 sq. ft. being sufficient floor space for a beast against nearly 100 in covered courts. Stalls are likewise economical of litter, 7 lb. being a sufficient daily allowance, while about twice this amount is needed in yards. The labour is, however, increased as compared with other methods owing to the necessity of individual feeding, daily removal of manure, and occasional grooming. The conservation of the manure will be less satisfactory than where it is kept firmly trampled in yards. Partially open courts are wasteful of litter and manure, but are

otherwise satisfactory except in very exposed situations. Cattle running together in lots are always liable to disturbance from restless or pugnacious individuals, and occasional beasts are prevented from getting their share of food. Lots usually settle down best if they have been grazed together for a month or two before being housed. In any case, horned cattle should have the tips of the horns removed before they are housed in lots, otherwise there is endless disturbance and a consequent loss of weight. A limited amount of stall or box accommodation is always necessary in order that bullying or frightened or sickly animals may be segregated.

Summer fatting of cattle may be carried out on the best sort of permanent grass without additional feeding, the land carrying a full-sized bullock to the acre and providing, in addition, some autumn and winter grazing for sheep. Well-managed rotation grass on good arable land will often do as well as this. Very careful adjustment of the number of cattle to the growth of the grass is necessary if the cattle are to make full progress without cake. On the one hand, if the grass gets overgrown the fibre-content rises and the digestibility falls; on the other hand, if the pasture gets too bare the cattle fail to get a full ration in the time (about eight hours in the twenty-four) that they spend in grazing. In the first case, the mowing machine should be used to keep the grasses under control. In the second, the farmer must resort to cake feeding. The type of stock should also be adapted to the quality of the pasture. In the chief grass-fattening districts of the Midlands the best fields are stocked with steers, the slightly poorer ones with heifers, and those of still poorer quality with barren and other cows culled from dairy herds. Of average feeding pasture about 1½ acres should be allowed per head, and some concentrate will often be needed during the latter part of the season. The concentrate used should be one of high energy value and low protein equivalent. Maize germ meal, maize meal, barley meal, and rice meal, made up for convenience in cube form, give satisfactory results. Live-weight gain is, of course, made at a much lower cost on summer pastures than on winter rations, but the grazier must buy his stores in a dear market (April and May) and usually sells a large proportion of his fat stock at the cheapest season—August to November.

The degree of fatness to which cattle should be brought before marketing depends on market conditions. It must be realised that during the last stage of feeding—that which makes the

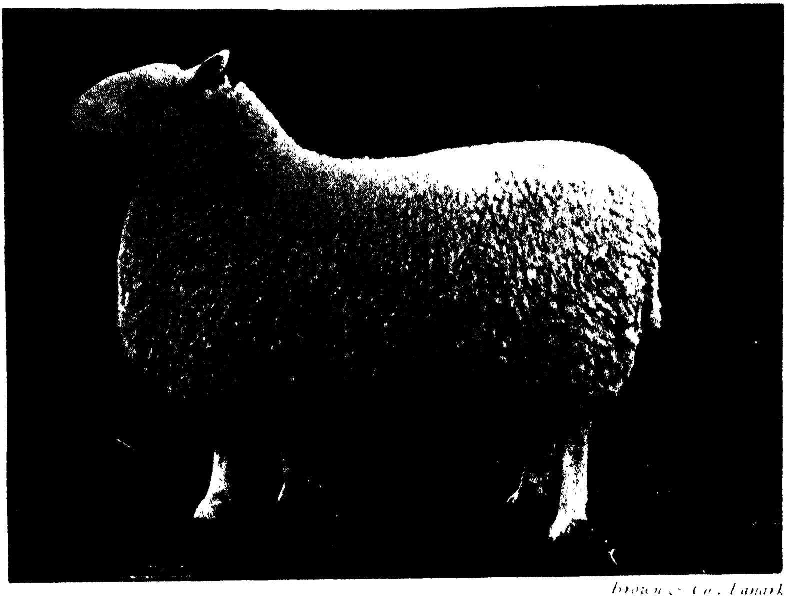


Farmer and Stockbreeder

A. English Leicester Ram

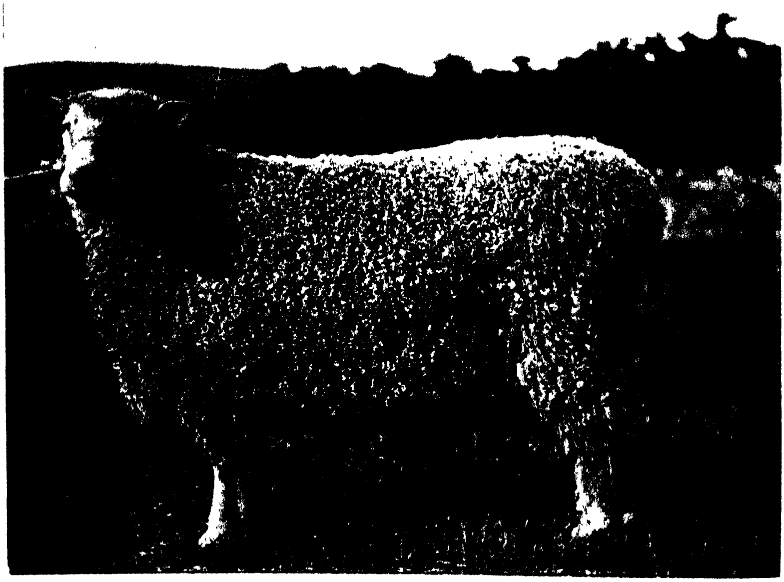
B. Border Leicester Ewe

PLATE XLVI



Brown & Co., Lanark

A. HALF-BRED SHEARLING RAM



B. WENSLEYDALE RAM

difference between "good" and "prime" condition—the live-weight increase is obtained at a very high cost. On the other hand, when prime cattle are scarce, the extra cost may be more than repaid in the increased value per hundredweight. The most serious error is to make cattle fatter than the butcher desires, for in this case a low price is obtained for an article with a high cost of production. Ordinarily fat cattle will dress about 57 per cent. of their live weight, or, say, 8 lb. to the stone. Prime cattle may reach 62 or 63 per cent., and exceptional animals in very high condition from 65 to 70. Very lean animals may yield under 50 per cent. of carcass. The largest items in the "sinkage" are the contents of the alimentary canal (15 per cent.) and the hide (7 per cent.). Dressing percentage will obviously vary considerably with the quantity of food contained in the stomach and intestines; cattle fasted and thirsty may weigh 70 or 80 lb. less than when full.

CARE AND MANAGEMENT OF BULLS

Bull calves intended for breeding should be kept in growing and thriving condition from the start. Those of the beef breeds are normally nursed by their own dams, though occasionally they are changed over to foster-mothers which yield relatively large amounts of milk. Dairy bull calves are often suckled by cows which, because they are "hard milkers" or for other reasons, are troublesome in the dairy herd. Alternatively they may be reared on the bucket. After the calfhood stage, bull calves should continue to be well nourished but not necessarily made fat. They should be housed in airy boxes, kept practically at outdoor temperature, and should have access to an open yard. Exercise is essential, and this may be provided by a run on pasture for an hour or two daily, or alternatively a walk in halter. Subsequent management is always easier if the young animals have been regularly haltered and led about. The feet must be kept in good shape by occasional trimming, and the coat should be kept clean by grooming and an occasional washing. A nose-ring is inserted before the animal is strong enough to cause trouble—say at the age of ten or twelve months. Either a rope or a pole should be attached (by means of a spring hook) to the nose-ring when the bull is led out, but control should normally be exercised by the halter, and the nose-ring kept in reserve in case of trouble. If further restraint is necessary, as it occasionally is in the case of

older dairy bulls, blinkers may be put over the eyes, so adjusted that the animal can see only the ground in front of it.

Bulls must be inspected for licensing before they are ten months old, and it is obviously important that they should be presented in good condition. Breeders not infrequently complain that bulls are rejected for no other reason than lack of condition, but it is obviously very difficult for an inspector to satisfy himself that the condition of a lean and somewhat ragged specimen is due entirely to its restricted diet. In the case of beef breeds—and to a less extent in that of dual-purpose types—capacity to fatten, and to fatten in the right way, is of fundamental importance, and it is impossible to say with certainty whether a lean animal possesses the capacity in the desired degree.

It is of obvious importance that bulls should be retained until the merits of their progeny can be assessed—*i.e.* in the case of a beef breed for about two years after the animal has been put into service, and in that of a dairy sire fully four years after use has begun. In fact very few dairy bulls are kept so long, chiefly because a large proportion become progressively more difficult to manage as they get older. Another factor is that if an old bull is kept on after his daughters reach breeding age, a second sire is required to mate with these, and the keep of two males is a very heavy charge in the case of the average herd of perhaps fifteen cows. There is no question that the solution of the bull problem, for the smaller sort of dairy farm, is artificial insemination; but large-scale breeders, and especially owners of pedigree herds, will probably continue to keep their own bulls even if they make some use of the artificial insemination service.

The bull box should be light and airy, and should preferably have access to a large open yard. Failing this yard, opportunity for exercise may be provided by means of an overhead wire with a runner to which the bull's nose-ring can be attached by means of a chain, or by one or other of a variety of devices. Where there is a yard outside the box the door communicating between the two may be of the portcullis type and be operated from the feeding passage of the box, or from outside, by means of a wire rope; this arrangement enables the bull to be restricted to the yard while his box is being cleaned and littered, or *vice versa*. It is easy to arrange that the bull may be secured, by his nose-ring, from the feeding passage, the animal being brought within reach by the offer of food. Again, a service pen may be so placed and devised

that the bull may serve a cow and be put back into his yard without being handled or being given any opportunity to attack his attendant. These various precautions may seem to be unnecessary in the case of good-tempered animals, but a large proportion of bulls are subject to occasional and unpredictable fits of viciousness.

Apart from the important matter of exercise, the bull must be kept fit by adequate nourishment and yet not allowed to become fat. A suitable ration for a mature animal of average size is 20 to 25 lb. of hay, with a few roots in winter and some green stuff in summer, and perhaps 2 lb. of the concentrate mixture that is fed to the milking cows.

If the bull-yard is laid with well-roughened concrete the animals' feet may not require much attention, otherwise the hoofs must be trimmed back when they get too long. When such attention is needed, some animals may be tied up and handled as horses are when they are shod, but many must be put in stocks, or alternatively, be hobbled with special tackle and thrown in order that the operation may be carried out.

CHAPTER V

SHEEP AND GOATS

SHEEP and goats, with certain intermediate species, are generally regarded as forming one group of the Cavicornia or hollow-horned ruminants.

The true sheep comprise a considerable number of wild species which fall into two rather distinct natural groups. The one includes the Mouflon (*Ovis musimon*) of Corsica and Sardinia, together with the closely related species of Cyprus (*O. cypria*) and of Asia Minor (*O. orientalis*); and the Urial (*O. vignei*) of Persia, Northern India, and Tibet. The other group consists of the Argali (*O. ammon*) of Western Siberia and the Altai; Marco Polo's sheep (*O. Poli*); and the Bighorn of Northern Siberia (*O. nivicola*) and of the Rockies (*O. montana*). The true goats include the Markhor (*Capra falconeri*) of Afghanistan and the common wild goat or Bezoar (*C. aegagrus*) of the Caucasus, Persia, and Crete. The Steinbok and the Tur are included in the genus *Capra*, while the Bharal or Blue Sheep of Tibet, the Barbary Sheep, and the Tahr of Nepal and Kashmir, represent types intermediate between sheep and goats, and are referred to separate genera.

Nothing is known for certain regarding the origin of domesticated sheep. The view most widely held is that the Asiatic Mouflon supplied most of the foundation stock, but the Urial and even the Argali have sometimes been regarded as the ancestors of some domestic types. The older view, to the effect that the wild ancestor must have been quite different from any surviving species, is not now accepted. The common goat is descended from the Bezoar, and the Cashmere goat from the Markhor, while the valuable Angora is generally believed to have been derived from a cross between the two.

Sheep are valued commercially for their mutton and wool, and occasionally also for milk. With some breeds, such as the Merino, wool is the primary product, while British breeds are kept mainly for mutton—wool being a secondary, if still an important, consideration. The points of the mutton sheep correspond rather closely to those of the beef ox, the valuable qualities

being a tendency to fatten early in life (early maturity)—a thick covering of lean meat and an even and not wasteful distribution of the fat. The head varies greatly with the breed, but should be of good depth and width, strong of jaw, and broad through the nose; the neck moderately short, and thick at its junction with the body; the body deep, wide, and square; the shoulder top wide, level, and well covered; the chest deep and wide, and the ribs well sprung or rounded; the shoulder neatly laid and thickly covered, and the region behind the shoulder well filled up; the hind quarters long, broad, and level, with the width well carried out to the rump; the gigot or leg of mutton thickly fleshed, and the flesh well carried down, both inside and out. The back should be wide and level throughout, thickly covered with firm, muscular flesh; the legs moderately short and set well apart, the bone neither too coarse nor too fine, but clean and hard. The thickness of the tail is a useful measure of condition or fatness. The carriage should be stylish and springy, indicating activity and robust health.

Sheep's wool is commercially by much the most important fibre of its kind, although other wools and hairs—for example, mohair, cashmere, alpaca, and camel's hair—are all used as textiles. Wool is used in the manufacture of a great variety of articles. The chief are, of course, articles of clothing for the inhabitants of the colder regions of the world, but carpets, tapestries, and blankets absorb a considerable quantity of certain classes. The characteristics of the wool fibre on which its value mainly depends are as follows:—

1. *Length*.—This varies from under 1 in. to over 2 ft., the coarser wools being generally the longer. Other things being equal, the longer wools are the more valuable.

2. *Uniformity in Length of the Different Fibres in the Staple*.—This is important, because, for certain purposes, the short fibres require to be separated and put to a different use, bringing a lower price.

3. *Strength and Elasticity*.—Strong, elastic fibres suffer a minimum of breakage in the process of manufacture and naturally give a strong yarn. Fine fibres are stronger in proportion to their size than coarse. The staple should be free from any weak part or "break," as wool with such a "break" cannot be combed without great wastage. The condition is generally due to the sheep having suffered a severe check during the period of growth

of the wool. In Britain the common causes of a "break" in the staple are a period of undernutrition or partial starvation, which may affect the whole flock (particularly in the case of hill sheep), and illnesses of various sorts. The weaker part of the fibre is that produced at the end of the period of malnutrition—*e.g.* just before the commencement of fresh growth on a hill grazing. In extreme cases the sheep casts part or the whole of its fleece.

4. *Fineness.*—The mean diameter of the fibres may vary from about $\frac{1}{1500}$ in. in the finer Merino wools to $\frac{1}{600}$ in. or more in the coarser long-wool fleeces. The smaller the individual fibres the finer the yarn that can be spun from them, and in yarns of the same weight the finer wool gives a softer and fuller character, which in turn gives the finished cloth a better appearance and "handle." Softness is due chiefly, but not entirely, to fineness of the individual fibres.

5. *Crimp.*—The aptitude of the different fibres to interlock depends on the fineness and extent of the waviness or "crimp." Fine Merino will often show more than twenty waves to the inch, while most Longwools give only three or four. Crimp also gives springiness or elasticity to the finished cloth. Felting further depends on the number of epidermal scales and on the extent to which their upper edges project. Fibres with a smooth surface, like those of the Lincoln or Wensleydale sheep, are naturally slippery. On the contrary, Merino or Down wool (which has the appearance under the microscope of a series of irregular flower-pots set one inside the other) felts readily. The wool of a healthy sheep will rarely felt or "cot" on the sheep's back because the fibres lie parallel, with the serrations all pointing in one direction, and because of the coating of oily secretion. "Cots" or felted fleeces do, however, occur, and have a low value.

6. *Colour.*—A clean white or pale lemon-coloured wool can be dyed to any desired shade, whereas coloured wools, or those containing a proportion of black or brown fibres, have a restricted use. Hence dark fibres are objectionable, and every endeavour should be made by the breeder to eliminate them by selection. Certain natural-coloured wools—*e.g.* "moorit" (brown) Shetland—have a higher value, for special purposes, than white wools.

7. *Lustre.*—Wools with large, flat, epidermal scales have a bright shiny appearance, whereas if the scales are small and the surface rough the wool is dull in appearance. High lustre and felting qualities are obviously incompatible.

8. *Behaviour to Dyes.*—True wool absorbs dye differently from what is called "kemp," which is a coarse and generally brittle fibre with a characteristic dead-white appearance. It does not absorb dye in the ordinary dyeing process, and hence causes unsightly marks in the cloth. Here, again, the breeder should make every effort to get rid of the fault by careful selection of his breeding sheep. Kemp is commonest in the wool of mountain breeds, and generally increases with the age of the animal.

9. *Uniformity of the Different Portions of the Fleece.*—Previous to its manufacture, fleeces are "classed" according to their general quality, and each fleece is then "sorted"—*i.e.* it is pulled to pieces and these are placed in separate lots according to quality. Classing is done either by the producer, the merchant, or in many cases by woolgrowers' co-operative societies. Sorting is normally carried out by the manufacturer who, however, may re-sell the lots that do not meet his particular requirements. Sometimes, as in the best Merino wools, the fleece is practically uniform throughout. In most sheep the quality varies according to the part of the body from which the wool is taken. That from the shoulder is generally the most valuable, being deep in staple, uniform, and fine. The neck wool is often finer, but is much less uniform; that from the breech, on the other hand, is both coarse and irregular. The wool-sorter divides the fleece into different "counts," the count representing the number of hanks of yarn (each 560 yds. long, according to the Bradford system), that could be spun from 1 lb. The count, as usually applied, is a measure of fineness, although in actual spinning the length of yarn that can be got from the pound of wool varies with the length as well as with the diameter of the fibres. A good average Merino fleece might give wool of 64 quality from the back part and 70's from the front. A typical Longwool (*e.g.* Lincoln) fleece sorted into its separate counts is shown in Fig. 37. Skirtings, cots, brand marks, and soiled locks are removed before or during the process of sorting.

Wool is manufactured by either of two methods. In the *worsted* process the raw material, after scouring, is combed so that the short fibres are removed. The latter are sold as "noil" to the woollen manufacturer, while the long fibres, arranged parallel to each other in a sort of rope, form "wool tops." The tops are spun into a rather firm, hard thread, the cloth made from which has a distinct thread structure and a bright appearance. The

important qualities in worsted wools are length, strength, uniformity, trueness, elasticity, lustre, and fineness. High felting qualities are generally not required. In the second or *woollen* manufacturing process the short fibres are not removed, length being unnecessary. The material is carded—that is, it is teased out into a thin web in which the fibres run in all directions. The

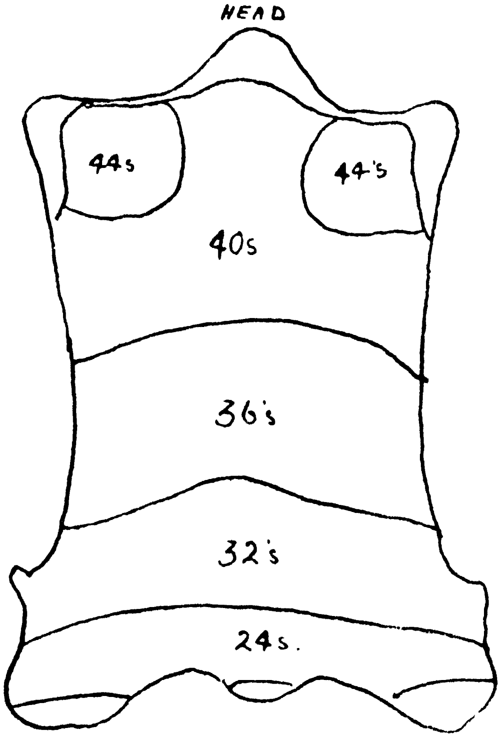


FIG. 37.—A Longwool Fleece, showing Sortings
(Jones)

carded "sliver," or rope, is condensed and spun without further treatment. The cloth is more or less felted by moisture and pressure, so that the fibres are interlocked in all directions and the thread structure becomes indistinct. The important qualities for this purpose are fineness, softness, and felting properties. A break in the staple is an unimportant defect, and lustre is not wanted, since the haphazard arrangement of the fibres would, in any case, conceal any natural lustre of the wool.

The value of natural or "greasy" wool will, of course, vary with the proportion of fatty and sweaty matter that it contains, as well as with its moisture-content. The "yield" of scoured wool, after the removal of the "yolk," may be has high as 80 or 85 per cent. in the Longwools, and may fall to 60 or even as low as 30 per cent. in some Merinos. The general run of British wools from unwashed sheep may give an average yield of about 70 per cent. Vegetable impurities, such, for example, as straw, burrs, grass seeds, or fibres—*e.g.* from jute packs or hemp string—are all very objectionable in wool, since they do not absorb dyes in the same manner. They are often difficult to separate, and their presence in large quantities may render it necessary for the wool to be carbonized (treated with acid and heat) in order to destroy them. Hence every endeavour should be made to keep them out. As extraneous matter is readily picked up during shearing, this process should be carried out on a clean floor or on a tarpaulin. Sheep are commonly branded after clipping. Tar should not be used for this purpose, but one of the materials officially approved by the wool trade. Sheep are frequently coloured ("bloom dipped") for sale purposes, and some of the materials used for this purpose permanently discolour the wool; such should be avoided. Shearing should never be done when the fleece is damp, otherwise the wool will deteriorate in storage. The fleeces must be stored under dry conditions.

From the farmer's point of view the weight of the fleece is obviously an important consideration. This depends on the size of the sheep and on the length and density of the fleece. Density is judged by grasping firmly with the hand. Single fleeces of modern breeds vary from 2 or 3 up to 15 lb., and exceptionally up to about 30 lb.

The wool breeds of sheep, as distinct from those in which mutton is the prime consideration, are all derived from the Merino of Spain. The Spanish sheep is now of little account but its descendants have covered a great proportion of the globe, and many distinct types have been evolved, notably in Australia, the United States, Germany, and France. Of these the American "C" type and Delaine Merino, as well as the French Rambouillet, are relatively large, robust, smooth-bodied sheep, with wool of good length (3 in.) and moderately fine quality, and capable of producing lambs of good quality for slaughter. At the other extreme is the American "A" type, small and of very poor

mutton form, with a very wrinkled skin and a heavy clip of very fine but short and very greasy wool. Merinos are best adapted to dry and at least moderately warm climates, and are a profitable type of stock for land at a great distance from centres of population.

BRITISH BREEDS

Omitting a few of minor importance and the Roscommon and Galway breeds of Ireland, there are thirty-two British breeds of sheep, falling into three main groups:—

(*A*) **Longwools** embrace the Leicester, Border Leicester, Wensleydale, Lincoln, Cotswold, Devon Longwool, South Devon, and Kent or Romney Marsh. These are, broadly speaking, the largest breeds. They are white-faced (except the Wensleydale), hornless, and have a fleece of long lustre wool which is used for worsted manufacture. They mature fairly early and fatten readily, but the mutton, at least of the older animals, tends to be coarse-grained and poor in flavour, and readily becomes too fat.

(*B*) **Shortwools** include six breeds that are ordinarily spoken of as Downs, and seven others. The Downs are hornless, with dark faces and legs, and generally a short, close fleece of relatively fine quality which is suitable for hosiery manufacture. Most have a strong flocking instinct and are docile, so that they are easily kept in folds. The mutton is generally of very good quality, with a high proportion of fine-grained lean meat and a fine flavour. Originally associated with the Chalk Downs, they have now spread all over Britain, except the mountains, and are kept under a great variety of conditions. The Down breeds are the Southdown, Shropshire, Suffolk, Hampshire Down, Dorset Down, and Oxford Down. The Oxford is not a typical member of the group but is intermediate between the Down and Longwool types. The remaining short-wooled breeds are the Dorset Horn and the Western or Wiltshire Horn (white-faced horned), the Ryeland and Devon Closewool (white-faced hornless), the Kerry Hill (speckled-faced hornless), the Clun Forest (dark-faced hornless), and the Radnor (brown or tan-faced).

(*C*) **Mountain Breeds**.—These have little in common except their generally small size, good quality of mutton, and their ability to live on mountain or moorland grazings. They include the Scotch Blackface, Swaledale, Lonk, Rough Fell, and the Dales-bred, all belonging to the black-faced, coarse-wooled,

horned type. The Derbyshire Gritstone is sometimes grouped with these, but is softer wooled and hornless. The others are the Cheviot, North-country Cheviot, Welsh Mountain, South Wales Herdwick, Exmoor Horn, Dartmoor, and Shetland. The quality of the wool varies widely even within particular breeds. The coarsest is used for carpet-making, the intermediate for Harris and other strong tweeds, and the finest for hosiery and flannel.

The Leicester (Plate XLV, *A*) is the oldest, or at least was the earliest improved of the Longwool breeds. It was evolved by Bakewell between 1755 and 1790 from the pre-existing Old Leicester type. The latter was large and coarse, late maturing, and of poor mutton type, though it bore a good fleece of long combing wool and was hardy and prolific. Bakewell effected a very great improvement in early maturity and in mutton qualities generally, but it is generally acknowledged that he allowed the fleece to deteriorate and the fecundity to decline. Bakewell's type would doubtless carry far too much fat for modern taste, but fat meat was at his time in demand. During and after Bakewell's time the Dishley Leicesters spread all over the country; they gave rise, as an offshoot, to the Border Leicester, and they were used in the improvement of all the other Longwools and of some other breeds as well. With the change of taste in favour of smaller and leaner mutton, the breed, as a commercial sheep in its pure-bred form, has declined in popularity, but it is still useful for crossing purposes.

The modern Leicester is a medium-sized Longwool of low-set and blocky conformation. The carcass weight of mature ewes is from 100 to 140 lb., rams reaching 200 lb. The head is wedge-shaped, the nose slightly Roman and rather thin at the bridge; the hair on the face white with a bluish tinge and dark spots, and the lips and nostrils dark. The forehead is covered with wool, the ears are bluish or white, long and thin; the neck is short and thick, and is carried almost horizontally. The fleece is fairly dense, of good length, and is fine, curly, and highly lustrous. The count is about 46/40. Good ewe flocks will clip about 10 lb. per head and tegs 12 to 14 lb. The mutton is of fair average Longwool quality.

The chief centre of the breed is now the Wolds in the East Riding of Yorkshire. Some flocks are still kept pure for ordinary commercial purposes, but there is a growing tendency to cross the Leicester ewe with the Suffolk ram in order to obtain a leaner

type of mutton with better flavour; other flocks are maintained in order to produce rams for mating with Mountain, or more generally, with " Masham " (Wensleydale × blackfaced mountain) ewes. Abroad, the breed has been successful in Australia, New Zealand, and Tasmania, and to a less extent in South America. It is also found in Canada and the United States, but there it has been merged to some extent with the Border Leicester.

The Border Leicester (Plate XLV, *B*) is descended from Dishley sheep that were brought to the Scottish Border district from about 1800 onwards. Whether or not any Cheviot blood was introduced in the formation of the Border type has been much disputed. English Leicester rams continued to be imported by Border breeders until about 1850, but since that time the types have been kept distinct. By 1869 the two types had so far diverged that the Highland Society decided to institute separate classes for each.

This breed is of similar weight to its relative, but is higher on the leg, with a high and straight underline. The head is long, rather thin through the nose and light behind the ears. The nose is aquiline, the whole head free from wool, and the lips and nostrils black. The ears are large, white with occasional black spots, and carried rather high. The neck is distinctly long, but thick at its junction with the trunk, and the head is carried gaily and high. The breed is exceptionally wide and level of back, and is very easily fattened. The modern tendency is to aim at a rather short and dense fleece. The wool is wavy and lustrous, with an average count of 48/44; 10 lb. is reached as an average clip in the best flocks, and 14 lb. is a common clip for well-bred and intensively fed ram hoggs. The Border Leicester is fairly hardy and extremely prolific. Flocks kept under good conditions will often produce 170 per cent. of lambs, and the ewes are good milkers. The chief use of the breed is the production of rams for crossing with Cheviot and Scotch Blackface ewes. It is admirably adapted for mating with the smaller and leaner breeds owing to its combination of size, early maturity, and a thin head—which last is an important feature in connection with parturition. Border Leicesters are largely bred in Northumberland and Cumberland and throughout all the lowland districts of Scotland, and the breed is common in Northern Ireland. A blue-faced strain with a finer fleece is bred in the vicinity of Hexham and is preferred locally for crossing with the black-faced mountain

breeds. The Teeswater is somewhat similar. The Border Leicester has been largely exported, and is probably the most widely known of the Longwools. In Australia it is the most numerous of all British breeds, and gives excellent results when crossed with the Merino.

Half-bred (Plate XLVI, *A*) or Border Leicester × Cheviot ewes are the common type of breeding stock on arable farms north of Yorkshire, and are an important commercial type in many grassland districts in the Midlands and elsewhere in England.[1] They are hardy, very prolific (rarely giving less than 150 per cent. of lambs), and excellent mothers, and when crossed again with Oxford, Suffolk, or other Down rams, produce an excellent type of butcher's sheep.

The Wensleydale (Plate XLVI, *B*) was produced originally by crossing the Dishley Leicester with an old, large, white-faced breed known as the Teeswater "Mug." The characteristic blue face and legs were derived from the half-bred Leicester ram "Bluecap," born in 1839. The modern type was fixed about 1860.

The Wensleydale is a large-framed sheep, rather long of leg and long of body. The depth of rib is good, but the back is less broad than that of the Leicester. The head is strong, highly carried on rather a long neck, and the forehead carries a tuft of wool. The fleece is long, similar in quality to that of the Leicester (46/40) but with a higher lustre. It is divided into locks of about pencil size and is open in character. Good ewe flocks average up to 9 lb. of wool. The face and legs are of a very characteristic deep blue-grey colour. Some strains produce a considerable proportion of black lambs.

The Wensleydale is probably the hardiest of the Longwools, but is notably narrower in build than the Leicester or Lincoln and is distinctly later maturing. The mutton is of good quality with, for a Longwool, a remarkably high proportion of lean meat. The breed is mainly found in the North and West Ridings of Yorkshire and in Lancashire. Its chief use is the production of rams for crossing with the various black-faced mountain breeds, both in the north of England and in the south-west of Scotland. Crosses with Swaledale ewes are known as Mashams (Massams) and those with Scotch Blackface ewes as Yorkshire Crosses.

[1] In many parts of England half-breds are erroneously called Border Leicesters. In parts of Yorkshire the name Bamshire (from Bamburgh, Northumberland) is used.

Masham ewes are often mated back to Wensleydales in the lower country, producing "twice-crossed" lambs. Both sorts are very useful commercial sheep for winter feeding. The Wensleydale is also the favourite breed for crossing with Herdwick ewes.

The Lincoln (Plate XLVII, *A*).—Before the era of live-stock improvement for meat production there existed in Lincolnshire a large, coarse breed of sheep, with a remarkably good fleece of long, strong, lustrous combing wool. For long the breeders of the Old Lincoln sheep held out against the introduction of Dishley Leicester blood, but eventually crosses were made, and the modern Lincoln undoubtedly owes something to the outside blood, which, although it temporarily diminished the size of the sheep and the length of wool, improved the fattening qualities and symmetry.

The Lincoln is the largest British breed. Mature rams in show condition occasionally reach 400 lb. live weight, and the average weight of the wethers (at twenty-two months old) shown at Smithfield in the thirties was practically 3 cwt. The Smithfield weights show the breed to be about 12 per cent. heavier than the Leicester. Ordinary commercial tegs reach carcass weights of 80 to 90 lb. at twelve months old. Compared with the English Leicester, the Lincoln is more massively built and has a rather longer and stronger head, which is generally carried a little higher. The ears are always more or less dotted with black. The wool is of great length, that of hoggs frequently exceeding 18 in.; it is very dense on the pelt, wavy, lustrous, and strong, but distinctly coarser (about 44/36) than that of the Leicester. The locks are as broad as two fingers and are less completely separated than in the Leicester. The clip is heavy; 12 lb. is not an uncommon average in good flocks, while ewe hoggs often give a stone and heavily fed ram hoggs as much as 2 st. of wool. In the show type a good deal of wool is carried on the hind legs below the hocks, and there is a top-knot of long locks.

The Lincoln is quite hardy, commercial flocks being kept on the fairly high and exposed wold and "heath" land of its native county. It is not remarkable for fecundity, 130 per cent. of lambs being considered a satisfactory crop. The quality of the mutton, at least of the older sheep, is generally poor. In Britain the breed has not spread far beyond its native county, most of the leading flocks being found in Lincolnshire and south-east Yorks, though there are numbers of commercial flocks in Nottingham and elsewhere in the east Midlands. Abroad, however, especially in

Australia and Argentina, the breed is in great favour on account of its value for crossing with the Merino. The cross-bred is large and readily fattened, and yields a heavy fleece of useful medium-quality wool. The well-known Corriedale breed, originally formed in New Zealand but now widely distributed throughout the world, was produced by fixing the characters of this cross, with some infusion of Leicester blood. In the past fifty years British breeders of Lincolns depended largely upon the export trade, and since this was not very active in the years preceding 1939, the breed was declining in numbers. Under the war-time system of paying flat-rate prices per pound for all fat sheep, irrespective of size, the breed rapidly returned to favour.

The Cotswold, formerly kept in large numbers on the limestone farms of Oxfordshire and Gloucestershire, is still of some importance in the United States, but only two or three British flocks survive. It is nearly as large as the Lincoln and of somewhat similar type but with a somewhat coarser type of fleece.

The South Devon (Plate XLVII, *B*) is a large, robust type of sheep found in Cornwall and South Devon. In many respects it resembles the Lincoln but is longer in body and, on the average, less squarely and massively built. The wool is dense, long, and curly, but coarser (about 36/32) than in the Lincoln, particularly at the breech. The mutton is of relatively good quality, with a high proportion of lean meat.

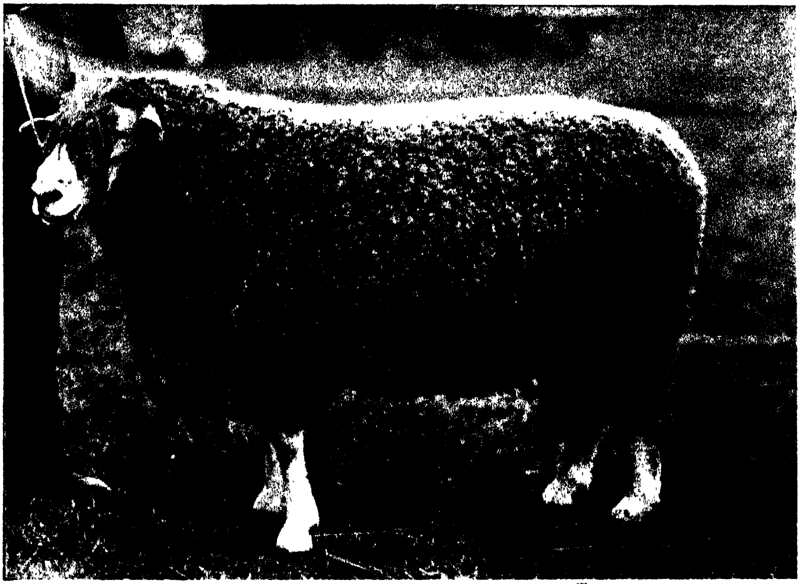
The Devon Longwool is smaller than the last (roughly equal to the Leicester in size) but somewhat irregular both as to size and type. The fleece is similar to that of the South Devon. The quality of mutton is again above the ordinary Longwool standard. The Devon is the predominant Longwool breed in North and East Devon and Somerset, but is tending to give way, like other Longwools, to smaller, leaner, and hardier breeds. For fat-lamb production Devon and South Devon ewes are frequently crossed with Down rams, the Dorset Down, Hampshire, and Suffolk being commonly used.

The Kent or Romney Marsh (Plate XLVIII, *A*) is an old breed native to the rich but cold, exposed, and damp grassland district from which it is named. Like all Longwools the modern breed is indebted to some extent to the Leicester, but it has retained many of its original characteristics and is in many ways the most distinct of the Longwool breeds. Of these it is the smallest, the mean weight being perhaps 5 per cent. less than that of the

Leicester. It is low of leg, stout-limbed, and long-bodied. Often it is low at the shoulder and deficient in heart girth in proportion to its development of hind quarter. The forehead is very wide and generally carries some short wool; the nostrils are black. The wool is denser than that of any other Longwool and is much finer in quality (50/46) though shorter and less lustrous, and sometimes rather coarse at the breech. The wool is classed as demi-lustre. The fleece is heavy, ordinary commercial flocks yielding an average of 8 or 9 lb., and pedigree flocks usually reaching over 10 lb. The Romney is hardy, does well on grass without hand-feeding, and is relatively immune from such diseases as foot-rot and liver-fluke that so frequently affect sheep on wet land. The sheep graze singly, rarely flocking of their own will. The breed is not notably prolific, giving perhaps 120 per cent. of lambs under ordinary conditions.

The Kent sheep is very numerously represented in the south-eastern counties, although a considerable proportion of the ewes are crossed with Southdown, Hampshire, or other Down rams. The lambs so produced fatten readily and are of excellent quality. Abroad the breed is very popular, notably in New Zealand, but also in South America, Australia, the Falkland Islands, and elsewhere. New Zealand now competes with England in supplying pedigree sheep of this breed to other countries.

The Southdown (Plate XLVIII, *B*) was the earliest improved of the Shortwool type, and was used in the improvement or formation of all the modern Downs, just as was the Dishley Leicester in the production of the modern Longwool breeds. The Southdown has existed for several centuries on the chalk hills of Sussex, and the old type, before the improvers had set to work, was described as a small, dark-faced, and occasionally horned breed, long in the neck, light in the fore quarter, long and narrow in the back, with a light, thin fleece. The hind quarter was, however, well developed, and the leg thickly fleshed. The first of the great improvers was John Ellman of Glynde, near Lewes, who started farming about 1780 and bred Southdowns with great success for fifty years. He avoided close inbreeding and, unlike Bakewell, he devoted close attention to the fleece and to the breeding qualities. Also he increased rather than diminished the size of his breed. Ellman's chief successor in the work of improvement was Jonas Webb, of Babraham, Cambridge, who began about 1821.

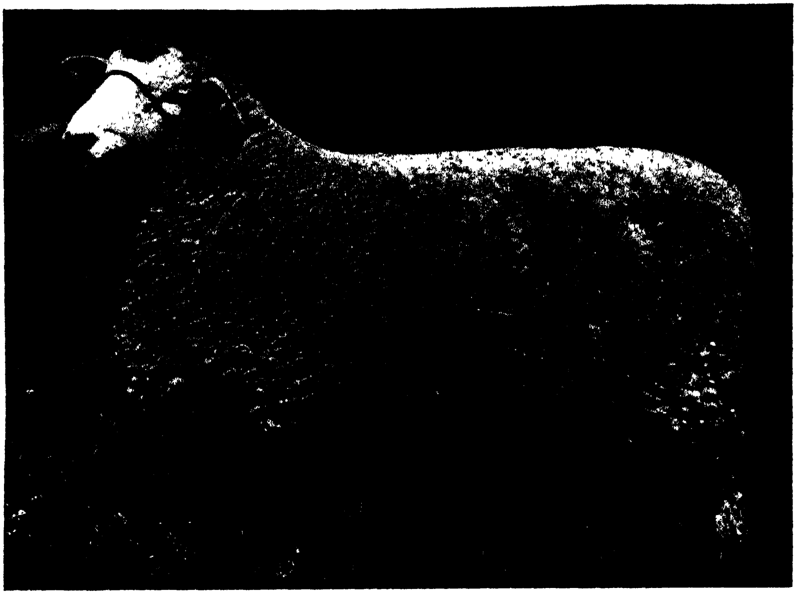


J. T. Newman, Berkhamstead

A. LINCOLN LONGWOOL RAM

Farmer and Stockbreeder

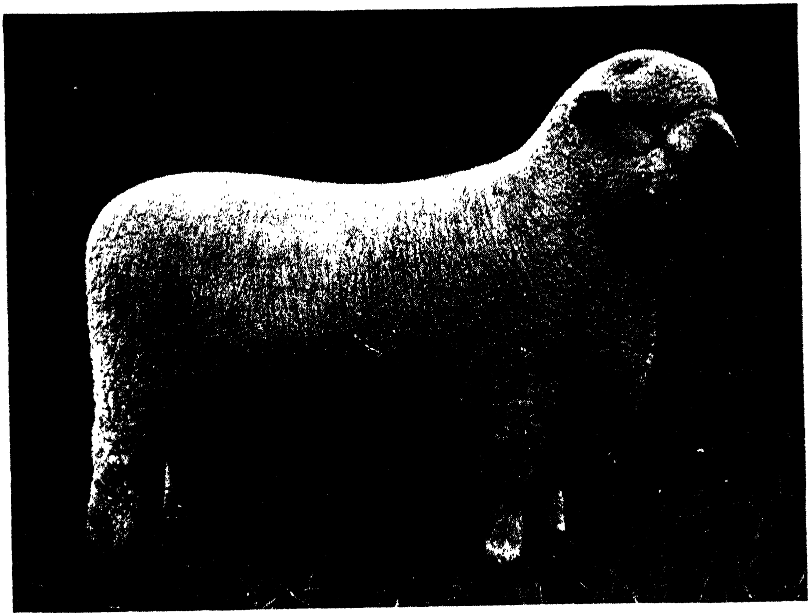
B. SOUTH DEVON SHEARLING RAM



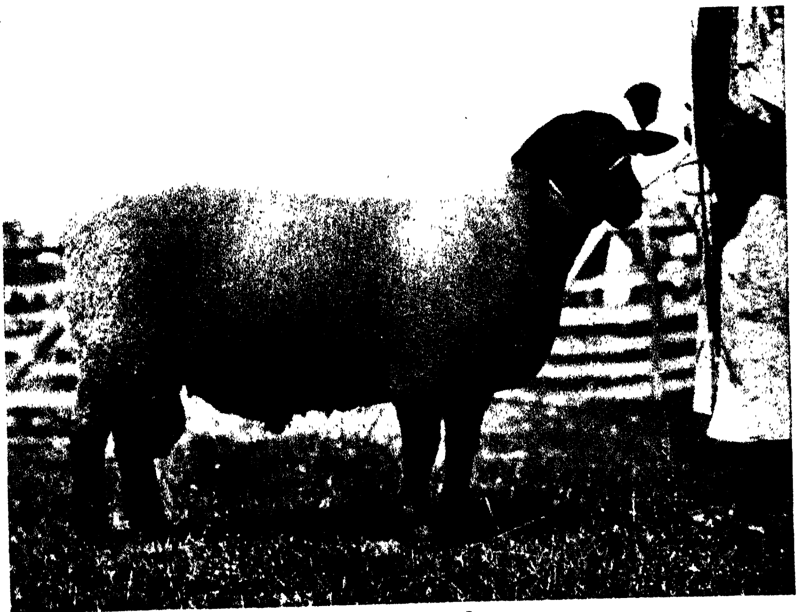
A. Kent or Romney Marsh Shearling Ram

Farmer and Stockbreeder

B. Southdown Shearling Ewes

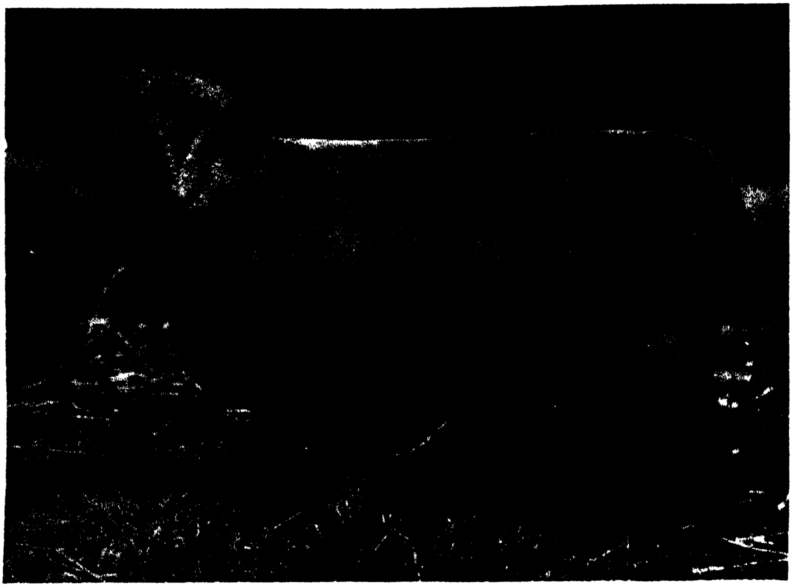


A. Shropshire Shearling Ram



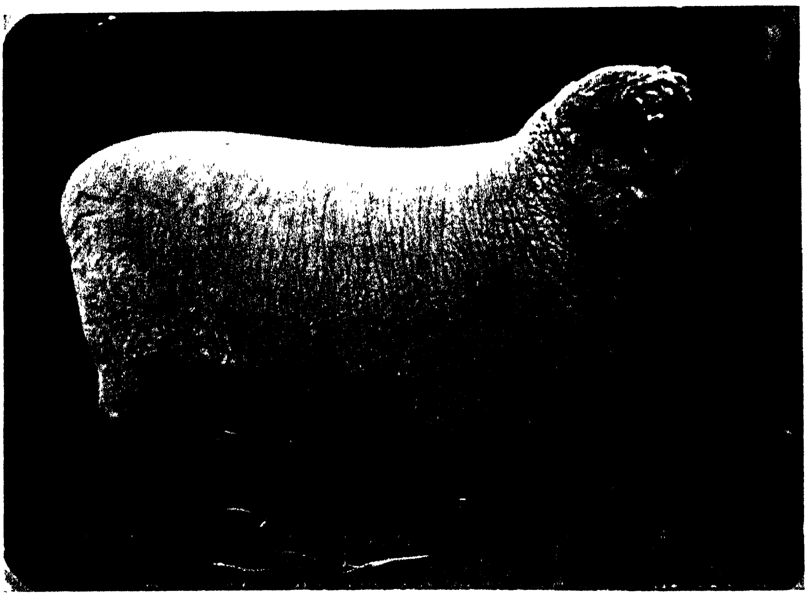
B. Suffolk Ram Lamb

PLATE L



Farmer and Stockbreeder

A. Hampshire Down Shearling Ram



B. Oxford Down Shearling Ram

The Southdown is distinctly the smallest of the Down breeds and attains, at maturity, less than two-thirds of the weight of the Lincoln. Full-grown rams of the better sort, in fat condition, weigh about 200 lb., and good ewes in breeding condition about 130 lb. The general build is very neat, compact, and symmetrical. The head is very wide, short from the eyes down, of an even mouse colour and is wooled over the forehead, but not round the eyes or over the bridge of the nose. The ears are short and are covered with short wool. The leg of mutton is remarkably thick and heavy. The wool is short (about 2½ in.), dense, and very fine (60/56), commanding the top price per pound for British wools. The clip in good ewe flocks may reach 4½ lb., or occasionally more. For quality of meat the breed is unsurpassed, and as a winner of carcass competitions it occupies a place comparable to that of the Aberdeen-Angus among cattle. The lambs mature and fatten very early and produce small fleshy joints with very little bone.

The breed is reasonably hardy, but below the average of the Down type in prolificness. Up till 1939 Southdown rams were largely used for crossing, and the cross-bred lambs, though small, ordinarily commanded a premium over all other market types. The loss of this premium under war-time conditions resulted in a great decline in the demand by commercial sheep breeders for Southdown rams. There had been some revival at the time of writing, but pedigree flocks in Britain were very few. The breed is still in widespread use in New Zealand for crossing with Romney Marsh and Corriedale ewes for the production of choice quality lamb.

The Shropshire (Plate XLIX, *A*) originated before 1850 in Shropshire and Staffordshire. It was produced from local sheep by crossing with the Southdown, and possibly, in earlier times and to a less extent, with the improved Leicester. Of these local types the two most important were those of Morfe Common, near Bridgnorth, and of Cannock Chase in Staffordshire. The new breed first attracted attention at the Royal Show in 1853, and in 1859 it was definitely recognized by being given separate classes. Although the type has changed considerably since those times, no further outside blood has been introduced.

In size the Shropshire stands about half-way between the Southdown, which is the smallest, and the Oxford, which is the largest of the Down breeds. The head is wide above, and short.

The former breed standard called for wool down to the nose, but a "clean" face, with the wool restricted to the poll, is now laid down. The change is to be commended, since wool on the face tends to collect grass seeds, burrs, etc., thus making for extra work on the part of the shepherd. The face and legs are of a soft black colour, sometimes a little mixed with grey. The ears are short and pointed. The general form is square and blocky, on short strong legs that are wooled almost down to the feet. The fleece is dense, of good length (fully 3 in.), and of typical Down quality (56/50). In good flocks the average clip will reach 7 lb. The wool is relatively free from dark fibres, though some are generally to be found about the head and legs. The Shropshire is very early maturing, and hence excellent for fat lamb production. The quality of mutton is good, but the carcass lacks something of the smoothness of that of the Southdown, and can easily be made too fat. The fertility is high, 150 to 160 per cent. of lambs being common. The breed is fairly hardy, adapts itself well to a great variety of conditions, and the rams are very useful for crossing with the leaner and later-maturing types of ewe. In Britain it is still most numerous in Shropshire and the adjoining counties. From about 1920 there was a marked decline in numbers; on the one hand the breed lost ground to the Suffolk and Oxford for crossing with long-wool and half-bred ewes and, on the other, as a foundation for commercial ewe flocks, to the Clun and Kerry Hill. Recently there has been some revival.

The Suffolk (Plate XLIX, *B*) was formed in the first half of the nineteenth century by crossing the old black-faced Norfolk Horned breed with the Southdown. The former had existed in East Anglia from early times, and was a very active, hardy, and prolific breed producing a light fleece and a very lean carcass. One small flock still survives. By 1850 the new type had been fairly well fixed, and by 1859 it was recognised locally as a definite breed. In 1886 separate classes were provided for it, for the first time, at the Royal Show.

Though slightly inferior in weight to the Oxford, the Suffolk is one of the larger of the Down breeds. The head is rather long, generally quite free from wool, and, with the legs, of an intense glossy black colour. The neck is rather long, the bone stout, and the legs free from wool. The fleece is of fair length and density and of typical Down quality (58/52). A good average clip would be 7 lb., but some choice flocks reach 9 lb. Dark fibres in the

wool are rather common, and the lambs are dark or parti-coloured when born. The mutton is full of lean meat and of very high quality. In carcass competitions in Britain the Suffolk competes strongly with the Southdown and the Mountain breeds. The prolificness is relatively good. On the light-land farms of East Anglia, where food conditions at mating time are often unsatisfactory, a fall of 130 per cent. is perhaps average. When the ewes have access to abundant green food at mating time, 150 per cent. or more is not rare.

In Britain large numbers of rams are used for crossing with Longwool ewes, the crosses being so good that they form a favourite type for exhibition at fat-stock shows. In the north they are now perhaps the most popular breed for crossing with half-breds, and are sometimes used on Cheviot draft ewes. The centre of the breed is still East Anglia, but there are many flocks in other districts of England and in Scotland. Canada, U.S.A., South and East Africa, and Chile have been the principal foreign markets.

The Hampshire Down (Plate L, *A*) owes its origin to the crossing of Southdowns with two old local types, the dark-faced, horned, Berkshire Knot and the Wiltshire, a white-faced, horned, and very light-wooled sheep that is still in existence. The breed was formed in the first half of the nineteenth century, and was first recognized by the Royal Agricultural Society in 1861.

The early Hampshire was nearly as large as the Suffolk, though shorter legged and more blocky. The recent trend has been towards a smaller type more nearly resembling the Southdown. The ears are long and are carried rather low. The wool on the head reaches below the level of and generally surrounds the eye. The shoulder top and breast are generally very wide and the leg is well developed. The wool reaches about 3 in. in length, is of nearly as good quality as Southdown and is very uniform (58/56), but only moderately dense, and dark fibres are rather frequent. A good average clip would be 6 lb. The face and legs are of a deep, rich, brownish black.

Hampshires are very rapid growers, lambs reaching great weights at weaning. They do not fatten quite so readily as Shropshires, nor do they produce so fine a quality of carcass as the Southdown. The breed is well adapted for folding on arable land, and is the favourite on the mixed Down and arable holdings

on the chalk formation, where the ewes generally lamb in January, and many of the lambs are sold fat in spring. The ewes breed earlier in the year than those of other breeds, excepting the Dorset Horn and Dorset Down. The Hampshire is not very prolific, a lambing percentage of 120 being regarded as good. In many flocks a large fall of lambs is not specially desired, as twins cannot easily be got ready for the early lamb market. Moreover, it is difficult on the chalk farm to produce fresh green food in July, and the ewes often go to the ram in poor condition. The heavy head and wide shoulder of the old type discouraged the use of the Hampshire for crossing with the smaller sort of ewes, but recent years have seen a considerable refinement in these points. Abroad, the Hampshire has met with a considerable measure of success in many sheep countries, and especially in North America, where it is now the most numerous of British breeds.

The Dorset or West Country Down was formed by mating Southdown rams with Hampshire ewes, and by crossing the product with the native western Down type. It may be described as generally similar to the Hampshire; it is, however, slightly smaller and rather more blocky in build; also, it shows more refinement in the head and bone, and has a distinctly lighter colour of face and legs. The wool resembles Southdown in quality (58/54). The ewes breed very early in the year, and often lamb down in November and December.

The Oxford Down (Plate L, *B*) is another breed that owes its origin in part to the same early types as produced the Hampshire, having been formed between 1830 and 1850 by crossing these with the Cotswold. Some Southdown blood was also introduced. Crossing of Downs and Longwools is often done in commercial flocks, but the Oxford is the only case in which the cross-bred type has been successfully fixed. The breed was first granted separate classification at the Royal Show in 1862.

The Oxford is the largest and heaviest of the Downs. In some respects it most nearly resembles the Shropshire, but apart from the difference in size the Oxford has a much longer and less dense fleece, and less wool on the head and legs. There is a top-knot of long wool, and the face colour is uniform dark greyish brown —lighter than in the Shropshire. The head, too, is longer, and the ears longer and thinner. The clip is heavy, reaching an average of 9 lb. in the better flocks. The wool is coarser than that

of the other Downs (52/48), and indeed only slightly finer than Romney Marsh. The Longwool blood shows up, too, in the carcass. As lambs or young tegs, Oxfords give meat of good quality, but at a greater age, say towards a year, the carcass tends to become fat and coarse, and the size of the sheep passes beyond the desirable limit. Oxford rams are very suitable for mating with the older ages of half-bred ewes. The Oxford cross was for long the most numerously represented on arable farms in the north, but in the years preceding 1939 the preference for leaner joints favoured the Suffolk at its expense. The breed is widespread throughout Britain, with its centre in Oxfordshire and Gloucestershire. Abroad it has proved successful in most districts where food is plentiful. The ewes are very prolific.

The Dorset Horn (Plate LI, *A*) is an ancient breed native to Dorset and the adjoining parts of Somerset, Wiltshire, and Hampshire, including the Isle of Wight. The breed is of medium size with white face and legs, and is horned in both sexes. The nose is pink or flesh-coloured, never black as in the Longwools. It is about similar in weight to the Shropshire, but is longer in body and generally more loosely built, with a lighter fore quarter and a somewhat narrower back. The wool is as fine as that of any of the Downs, excepting only the Southdown and Dorset Down, but is rather less uniform in quality (56/50). It is clear white in colour when scoured, and is free from dark fibres, whereas that of most Downs is creamy white, and often contains black or brown: 5 lb. is reckoned a good average clip for ewes. Lambs are normally shorn in their first summer and clip 2½ to 3 lb. The quality of the mutton is good, but the carcass usually lacks the thickness of flesh of that of the typical Down. The breed is quite hardy, and well suited to the chalk farms of its native district, consisting of rather poor arable and dry semi-upland pastures. The ewes are very prolific, frequently giving 150 per cent. of lambs, and are excellent milkers. Their most striking peculiarity is that they will often take the ram as early as April or May, thus lambing in October-November. Milk-fed fat lambs may thus be produced by Christmas. Dorset and Hampshire Downs have something of the same peculiar habit, but not in the same degree. Occasional sheep of other breeds also breed out of season. Dorset Horn ewes were at one time widely used for the production of " out-of-season " lamb, but the extensive importation of frozen lamb, chiefly from New Zealand (Canterbury lamb), made the

practice unprofitable. A proportion of Dorset ewes will breed twice a year, but no satisfactory or permanent system of this kind has ever been found possible. The ewes cross well with Down rams, such as Shropshire, Dorset Down, and Hampshire, giving excellent lambs for early fattening. The breed has been extensively exported to Australasia and North America.

The Wiltshire Horn (or Western) Sheep is an old breed that at one time was nearly extinct but has been revived. A considerable number of small flocks are to be found in Northamptonshire and Anglesey. The Western is a sheep of good size, somewhat resembling the Dorset Horn, but of rougher conformation. The skin is often spotted with black, and the breed is peculiar in that it produces practically no wool. Such fleece as it possesses generally falls off in spring. The breed is hardy, and thrives well on grass throughout the year. The rams are used, especially in north Wales and the English Midlands, for crossing, the crossbred lambs being quick growers and coming early to market.

The Ryeland (Plate LI, *B*) is descended from a very small and very fine-wooled breed that was common in the west Midlands during the eighteenth century, and probably much earlier. In most districts this type seems to have been bred out of existence by repeated crossing with Leicesters, but in the poor and sandy tract in south Hereford (Ryelands) many of the original qualities were retained, along with something of the size and fattening qualities of the Dishley sheep. The Ryeland is still a comparatively small breed, lighter than the Shropshire but heavier than the Southdown. The face is of a dull white colour with dark nose, and is wooled down to the eyes. The general symmetry is good and the sheep is well covered with firm flesh. The wool is of good quality (56/50), not so fine as Southdown, but deeper in the staple and of a clear white colour. Good flocks give an average clip of about 6 lb. The carcass is blocky and thickly fleshed, but with rather more fat than that of the Downs. The rate of growth of the lambs is only fair. The Ryeland is moderately prolific, and thrives on cold, damp, and inferior land with a minimum of hand feeding. It is kept entirely as a grassland breed, *i.e.* it is rarely folded on arable crops. The home of the breed is still the southern part of the Welsh Border area, but pure-bred flocks are maintained in many parts of England. At one time the Ryeland seemed to stand in danger of being ousted by the Shropshire,

which is its neighbour on the north side; now its chief competitors are the Clun Forest and the Kerry Hill.

The Kerry Hill (Wales) occupies a position intermediate between that of the Down and that of the true mountain breeds. Geographically, and to some extent as regards its descent, it is midway between the Shropshire and the Welsh Mountain. Its home is the Kerry Hills district of Montgomeryshire. In size it approaches the Shropshire. The face and legs are black-and-white, with the black concentrated at the nose and feet, and there is a tuft of wool on the forehead. The wool is of Shropshire type, but generally somewhat coarse on the breech (56/48). The ewes are very prolific and good nurses. The quality of the mutton is good. The Kerry ram is the most commonly used for crossing with Welsh Mountain ewes, and again the Kerry ewe is often crossed with the Shropshire or Hampshire for the production of fat lambs. Some exportations have been made, but the breed has not yet become generally known abroad. The Breed Society dates only from 1899, although the breed has existed in very much its present form for about eighty years.

The Devon Closewool is native to the area lying between Barnstaple, South Molton, and Blackmore Gate in North Devon. It is derived from crosses between the Devon Longwool and the Exmoor Horn. Some of the flocks date from the end of the nineteenth century, but it was not until 1923 that a Breed Society was formed. Intermediate in size between the two parent breeds, and hornless, the Closewool otherwise approaches more nearly to the Exmoor Horn, being compact in build, thickly fleshed, and carrying a dense fleece of useful medium-quality wool (50/46). It may be described as like a small Romney Marsh, but it is shorter-bodied in relation to its height. The Closewool is a hardy breed, admirably suited to semi-upland conditions and living on grass for the greater part of the year.

The Clun Forest is an old local breed which originated in the Clun district of Shropshire, and was formerly restricted to the hilly districts of Shropshire, Radnor, and Montgomery. It is related to the Kerry Hill but carries more Shropshire blood. The breed is dark-faced, hornless, of medium size and, like the Kerry Hill, is notably hardy and prolific. It may be said to be intermediate between the Down and mountain types. The weight of fleece is about 6 lb. and the quality of the wool is similar to that of the Ryeland.

In recent years the breed has risen in popularity very rapidly, and it is now to be seen in large numbers not only in the Welsh Border country but in the Midlands and south. The ewe flocks thrive on pastures with little hand feeding, and are said to require very little shepherding. The wether tegs are frequently fattened on roots and settle down well in folds. If the ewes are mated to Down rams—*e.g.* Hampshire or Suffolk—the lambs fatten readily on leas and reach good weights.

It is common practice to put Clun ewe lambs to the ram at an age of eight or nine months. The usual expectation is that about 60 per cent. will conceive.

The Radnor is native to its name county, and in its economic characters resembles its geographical neighbours, the Clun and the Kerry Hill. The original breed was tan-faced like the Welsh Mountain, rather small, and very hardy. Some crossing with the Kerry Hill and Shropshire increased the size with some sacrifice of hardiness. There was, at the time of writing, no breed society.

Mountain Breeds.—The Blackfaced mountain type seems to have been first known in the Pennine Chain, and all the modern varieties of it appear to have a common origin in this district.

Of these the **Scottish Blackface** is now the best known and is the most numerous of all British breeds. It must have reached the southern uplands of Scotland several centuries ago, but was not introduced into the Highlands till about 1770. Previous to this time the Highland grazings were stocked mainly with cattle, and what few sheep there were belonged to the old Celtic soft-wooled type, which is still to be met with on some of the Western Isles. The Scottish Blackface (Plate LII, *A*), when reared in a true mountain environment, is a small sheep, but when heavily fed for fat-stock shows it reaches a weight greater than that of the Southdown or Ryeland. The face and legs are either black or "brockit," *i.e.* black with white patches, the latter being preferred, though excess of white is objectionable. The head is rather short and, in show specimens, very deep and strong at the nose. The horns of the ram are large, coming out level with the head and forming a wide spiral. The fashionable type of wool is long, nearly reaching the ground, and of a coarse and hairy character (40/28) but free from kemp. Some stocks have a finer and softer wool that can be used for rough overcoatings and

blankets, but most of the wool goes for carpet manufacture. The average clip under mountain conditions is probably about 4 lb., and the best flocks rarely exceed 5 lb. The general conformation has been immensely improved in recent times, and the modern sheep has a good back and leg of mutton, though the wither, as in all mountain types, is often narrow and sharp. The quality of carcass, whether as lamb or mutton, is first class. The tail is naturally shorter than in other breeds, reaching only to the hocks; as in other mountain breeds, it is frequently left uncut.

The Blackface occupies practically all the heather-clad or "black" hills of Scotland and Northumberland up to altitudes of 3000 ft. The highest grazings formerly carried wether stocks, the male sheep being kept on till they were two, three, or even four years old, but many such stocks have been displaced either by breeding ewes or by deer. Most of the lambs not required for breeding are now sold either fat from the hills in the latter part of summer, or as stores in autumn. On the higher grazings the Blackface is kept pure, while on the lower hills the ewes are crossed with Border Leicester or, in some districts, with Wensleydale rams. The cross lambs, known in the first case as "Greyfaces," "Mules," or "Crossbreds," and in the second as "Yorkshire Crosses," make excellent mutton at from seven to fifteen months old, though some are sold as fat lambs. The Blackface is exceedingly hardy. Generally, the ewe hoggs destined for breeding are sent to the low country to be wintered (on grass only), but the ewes live on the mountain throughout the year and get no artificial feeding except a little hay, and that only when the ground is covered with hard-frozen snow. The ewes are prolific. Under hill conditions twins are not generally wanted, but good draft ewes when taken to the low country give up to 140 per cent. of lambs.

The Lonk is found in the mountainous district of west and south-west Yorks, east Lancs, and north-west Derbyshire. It is a larger, longer-bodied, and rather longer-legged sheep than the Scottish Blackface, with often more white in the face. The tail is long. The fleece is considerably finer (50/44) and both denser and heavier (6 to 7 lb.) than that of the Scottish. The quality of the mutton is excellent, but the breed is distinctly less hardy than either the Scottish Blackface or the Swaledale. Wensleydale and Leicester rams are those principally used for crossing, where crossing is done.

The Swaledale (Plate LII, *B*), another useful and hardy breed, is also somewhat larger and longer-bodied than the Scottish Blackface. The fleece is shorter and finer in front but is coarse on the breech, and kemp is quite as common. The face is black or dark grey with a "mealy" (grey) nose, and the legs are spotted. There is usually a good deal of black wool on the nape and throat. Swaledale lambs are said to fatten rather more readily than Scottish Blackfaces and the ewes to milk rather better, but the hardiness is probably not so good. This breed is found from Swaledale westwards to the Pennines and into Westmorland. Where crossing is done the Wensleydale ram is used, and the female progeny, known as Masham ewes, are a common type of breeding stock on grassland farms.

The Rough Fell, also known as the Kendal Rough Sheep, is a closely related breed found in an area centred on Kendal and embracing parts of the West Riding of Yorkshire and of Westmorland. It is larger, somewhat rougher in conformation, and shorter wooled than the Scottish Blackface, and shows a brownish tinge in the face. It is regarded as a hardier sheep than either the Swaledale or the Lonk.

The Dales-Bred is a rather larger type with a heavier fleece. It is found on the lower and better grazings in the same area. The wool approaches that of the Scottish Blackface in quality (40/32) and the ewe fleece averages about 5 lb. Older ages of ewes are commonly crossed with Wensleydale or Teeswater rams.

The Derbyshire Gritstone, native to the high Peak district of Derbyshire, has the softest wool (50/46) and the closest fleece of all the breeds of the Blackface type, and is further distinguished by the absence of horns. The face and legs are mottled with black and white.

The Cheviot (Plate LIII, *A*) is regarded as derived from the ancient Celtic tan-faced breed, and would thus be related to the Welsh Mountain and to the old soft-wooled sheep of the western Highlands and Hebrides. It has existed on the hills of southern Scotland from very early times, though formerly the breed was much smaller and probably finer-wooled than now. There are some records of crossing with Lincolns and Leicesters about the end of the eighteenth century, but the improvement in size and in mutton qualities has been accomplished mainly by selection. The Cheviot is of medium size, reaching, when intensively fed, about the same weight as the Shropshire. The size of

hill-bred sheep naturally depends on the abundance and quality of the herbage. Mature rams of the best class, in show condition, weigh over 200 lb. The head and legs are white, with occasionally a shade of tan, and covered with rather hard, short hair. The head is rather short and very strong through the nose; the ears short and carried very high, giving the animal a very characteristic alert appearance. Short horns still occasionally appear—perhaps to the extent of 5 per cent.—in males. The tan colour of face is gradually being eliminated. The wool is of fine quality (56/48) but with a harsher handle than typical Down wool, of medium length (3 to 4 in.), and quite dense on the pelt. It is largely used for the manufacture of tweeds. Kemp is not common, but does occur. Mountain flocks clip from 3½ to 5 lb., and the better sort of ram hoggs reach 10 or 12 lb. The general conformation is good. The body is distinctly long and the back sometimes slack; the hind quarter is generally good, but the fore quarter, as in most mountain breeds, tends to be proportionately light and the shoulder rather sharp. The mutton quality is excellent, and the breed and its crosses (especially those from Southdown and Suffolk rams) are often very successful in carcass competitions. The Cheviot is hardy, but distinctly less so than the Blackface. In Scotland and the north of England it is chiefly to be found on the lower and more grassy hills, the heather land being given over to the Blackface. Cheviots are also kept as "park" sheep, *i.e.* on semi-upland enclosed land, and are then wintered with some turnips and other artificial food. The breed is prolific under good conditions and the ewes are excellent milkers. Hill Cheviots are very active and difficult to confine.

There are two main centres of the breed, the one in southern Scotland and the north of England and the other in Caithness and Sutherland. North-country sheep are larger and leggier, somewhat less compact in build, and longer of head and ear. The ears, also, are carried lower. They have finer but rather more open coats and tend to be less well clad over the belly. They require rather better food conditions than the true hill type of the Border area. A separate flock book for North Country Cheviots was established in 1946.

On the better hill farms the older Cheviot ewes are crossed with Border Leicesters, and on certain farms only half-bred lambs are produced, the Cheviot ewe stock being replenished from outside sources. Half-bred ewe lambs are in very keen demand for

breeding, and command a much higher price than wethers of the same cross. Half-breds produced from north-country Cheviot ewes are larger and more prolific than the corresponding progeny of Border ewes, though they require somewhat better food conditions. Draft Cheviot ewes are mated either with Border Leicesters or Suffolks. Cheviot ewes and ewe lambs are often taken far south into England for breeding purposes, and there are colonies in Brecon and on Exmoor. The breed has met with some success in Canada, the United States, and New Zealand.

The Welsh Mountain (Plate LIII, *B*) is an original Celtic breed that has been kept almost free from extraneous blood. It is the smallest of the breeds here described, reaching about half the weight of the Leicester or Oxford and not much more than two-thirds that of the Southdown. The Welsh sheep is rather long bodied, light in the fore quarter, and the face and legs are either all white or have patches of a light tan shade—the latter being commoner and preferred. The rams only are horned. The breed embraces several types, including a larger improved type on the more fertile farms with some low ground and smaller types on true mountain land. The wool of improved sheep is short, fine, and dense, comparable to Shropshire or fine Cheviot in quality (54/46), but that of the true mountain type is often coarse at the breech and contains much kemp. An average clip for ewes is 2½ lb., rams reaching 5 or 6 lb. The mutton is comparable in quality to that of the Southdown, Cheviot, or Blackface, and indeed is regarded by many judges as the finest procurable.

The Welsh is a hardy breed, living on the higher mountains during summer and being brought down to lower levels for wintering and lambing. The sheep are very active and rather wild, and hence are very difficult to confine. The ewes are excellent breeders and nurses. Draft ewes may be mated with Southdown rams to produce choice small fat lambs. For larger fat lambs the Wiltshire Horn is preferred. Where the produce is to be carried on to the teg stage, Kerry Hill or Clun rams give good results. The breed is found throughout the whole of the mountainous district of Wales, the population being densest in the north. A black strain of the breed exists, but is generally kept in lowland parks.

The South Wales Mountain is a rather leggy type with a

very kempy fleece, suitable only for carpet manufacture. It is found in Glamorgan and Monmouth and in parts of Carmarthen and Brecon. It is the largest of the Welsh types.

The Herdwick (Plate LIV, *A*) is a breed of rather striking peculiarities found in the bleak, exposed fells of the Lake District. Its origin is quite unknown, although there is a tradition that the foundation stock came from a Scottish or Norwegian vessel that was wrecked on the Cumberland coast two or three centuries ago.

The size is rather less than that of the Blackface mountain type, though varying a good deal with the quality of grazing. The rams are generally but not always horned, while the ewes are hornless. The face and legs of the lamb are of a deep blue-black colour, becoming grey and sometimes eventually white with age. The wool, particularly that on the belly, is often mixed with grey; it is long and coarse (40/32) and contains much more kemp than that of the Scottish Blackface. Ewes clip from 3 to 5 lb. according to conditions, and rams up to 9 or 10 lb. The shoulder top is generally sharp and the breed is late maturing, but the mutton is of fine texture and flavour. The ewes are sometimes not made to bear lambs till they are three years old—a year later than the normal age. The Herdwick is generally regarded as the hardiest of all British breeds; the sheep subsist largely on heather and juniper, and survive long periods of storm. Draft ewes taken to the low country are generally crossed with Wensleydale, Leicester, or Border Leicester rams, and the progeny make excellent butchers' sheep. The Wensleydale is the ordinary cross under hill conditions. The breed is declining in numbers owing to the progress of afforestation in its home area.

The Exmoor Horn or Porlock (Plate LIV, *B*) is an ancient breed native to Exmoor and the Brendon Hills in North Devon and West Somerset. It is of small size, horned in both sexes, with white face and legs and a black muzzle. The fleece is of the Cheviot type, but rather longer and stronger and coarser at the breech (56/40). Ewe flocks give clips up to 5 lb. The general conformation is compact and neat, with a peculiarly rounded symmetry. There is rather frequently a deficiency behind the shoulder. The breed is hardy, but the ewes generally get some roots and hay in winter. The mutton is of good quality.

The Dartmoor, like the Oxford Down, Kerry Hill, and Clun, cannot rightly be classified in any of the three main groups of

breeds. Though originally a Moorland breed, the Dartmoor has been so increased in size and improved in form that it must now be considered a Longwool. Like the true Longwools it owes something to Dishley Leicester blood.

It is larger than any of the mountain breeds proper, and hornless—short stubs being seen exceptionally in rams. The face and ears are white with black spots, the latter generally somewhat concentrated towards the nose. The fleece is long, curly, and lustrous, of coarse Longwool quality (36/32), and the clip is heavy. The sheep is long-bodied, strong-limbed, and well covered with firm flesh. The ewes are wintered on grass and hay, and lamb in the beginning of March. The breed is rather late-maturing but produces yearling wethers of fine quality. Older ewes are crossed either with Down or with South Devon rams. A white-faced strain is separately registered.

The Shetland is an interesting breed, so far little improved, but with certain potentially valuable characteristics. It is very small, slow-maturing, and thin-fleshed, though the texture and flavour of the mutton in well-fed sheep are good. The colour is black, grey, or brown (moorit), often with white patches, or entirely white. The white and moorit wools command the highest prices. The fleece is light and of very mixed quality but contains a proportion of very fine soft wool which commands a higher price than that of the Southdown. In Shetland the sheep are not shorn, the loose wool being picked off at intervals and the finest sorted out for the local industry of shawl-making. The breed, like others in Northern Europe, is naturally short-tailed. The rams are horned, the ewes generally hornless. At one time the breed occupied the whole of the Shetland Islands, but it has given way to some extent before the Blackface. Crosses with the Cheviot are useful both for wool and mutton.

COMMERCIAL TYPES AND CROSSES

It will be clear from references in the preceding pages that certain areas of the country breed far more sheep than can be fattened locally, and that some districts will have surpluses of ewe lambs suitable for breeding. The surplus is sold, and is moved into areas where the flocks are not self-supporting. The following are the more important classes of stores and breeding animals that pass through markets:—

Store Lambs.—A variable but rather small proportion of mountain wether lambs are sold to butchers direct from the grazings where they have been bred, but the bulk are marketed as stores in August and September. The main sources are the Highlands and southern uplands of Scotland, the northern counties of England, the Pennine region, and Wales. The mountain breeds have a limited capacity for growth, and in any case are not very suited for folding on roots, hence the great majority are fattened on pastures, aftermaths and rape, and reach the fat market mainly from October to December. They yield small carcasses of between 25 and 35 lb., which in normal times command a high price per pound. Ewe lambs are in demand for breeding, and in most areas only culls can be bought at prices which make it possible to fatten them at a profit. The typical product of the lower hill areas in the same regions and in Caithness and Sutherland is a cross between a mountain ewe (Blackface, Cheviot, etc.) and a Longwool ram. The Border Leicester × Cheviot ewe lambs (Half-breds) are in great demand for breeding, and few are fattened as tegs; but the wether lambs are a fairly important class of store. The breeders' demand for Longwool × Blackface ewe lambs (Greyface, Mule, Masham) is not so great, so that many of these, as well as the wethers, are available for fattening. Greyface and similar crosses are commonly run on lowland pastures for the earlier part of the winter and finally fattened off on roots, hay, and concentrates, reaching the fat market mostly from March till May; they produce choice carcasses of the size (50 to 60 lb.) that the consumer prefers at that time of the year.

Apart from mountain and hill areas, the chief sources of store lambs are: (1) Part-arable farms in southern Scotland, Northumberland, and Cumberland (crosses between Suffolk or Oxford rams with Half-bred or Mule ewes). (2) The Welsh border area (Kerry Hill, Clun, etc., and crosses of these breeds with Down rams). (3) Kent (Romney Marsh wether lambs and crosses between the Southdown ram and the Romney Marsh ewe). (4) The chalk area, from Dorset to Norfolk (mainly Downs, such as Hampshire, Suffolk, and Hampshire-Oxford crosses). The lambs from these four areas are naturally available earlier than those bred on the hills, the largest sales taking place in June and July. The more forward lots are fattened off on aftermath, rape, etc., but the majority are folded on roots and provide the bulk of the supply

of mutton from December till March, yielding carcasses of about 70 to 80 lb.

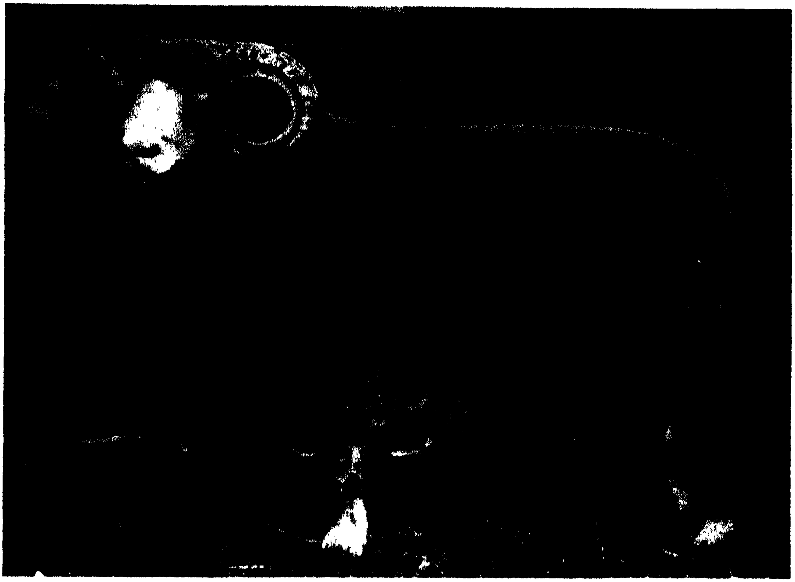
Ewe Lambs.—The mountain-sheep farmer normally retains the best of his ewe lambs for his own flock, selling his "seconds" to farmers in lower hill areas, who use them to produce cross-bred lambs. As already noted, there is a sale for some of the cross-bred progeny for breeding, the demand for Half-breds being especially strong. Many downland farmers also make up lots of "second" ewe lambs which are bought by other breeders.

Young Ewes.—Some breeders hold over their surplus ewe lambs and sell them at about eighteen months of age (theaves or gimmers), when they are ready for breeding. There are also some specialists who have suitable areas of lowland pasture and who buy ewe lambs and sell them as theaves a year later. Many breeders in the Welsh border counties keep all but the poorest of their ewe lambs and sell these females at two and a half or three and a half years old.

Draft Ewes.—Under comparatively rigorous conditions for any particular breed the death-rate among ewes tends to rise after about five years. On the other hand, rich land tends to make ewes too fat for breeding. Hence it is often advantageous to draft ewes from poorer to better farms at "three-crop" (four and a half years old) or "four-crop" (five and a half years old). The latter are often fattened with their next crop of lambs, but the former may produce two further crops of lambs in the second flock. There is a large demand for draft ewes, the sales mostly taking place shortly before the breeding season, *e.g.* in May for Dorset Horns and Dorset Downs, and in September to October for mountain breeds.

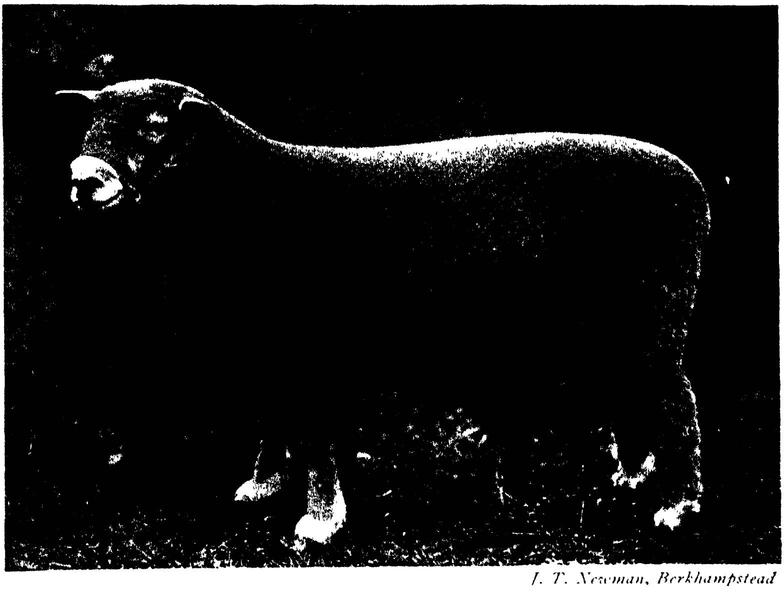
SHEEP BREEDING, REARING, AND FEEDING

It seems necessary to begin this section with an explanation of the names that are applied to sheep of the different sexes at various ages. Age in sheep is reckoned from the time of shearing, which in this country is normally done for the first time at the age of fourteen to sixteen months, and at yearly intervals thereafter. The term *lamb* is not very precisely limited, being sometimes confined to the period before weaning and sometimes extended to cover the first six, eight, or occasionally ten months of the animal's life. However, at some time in autumn, lambs become



Farmer and Stockbreeder

A. Dorset Horn Shearling Ram



J. T. Newman, Berkhampstead

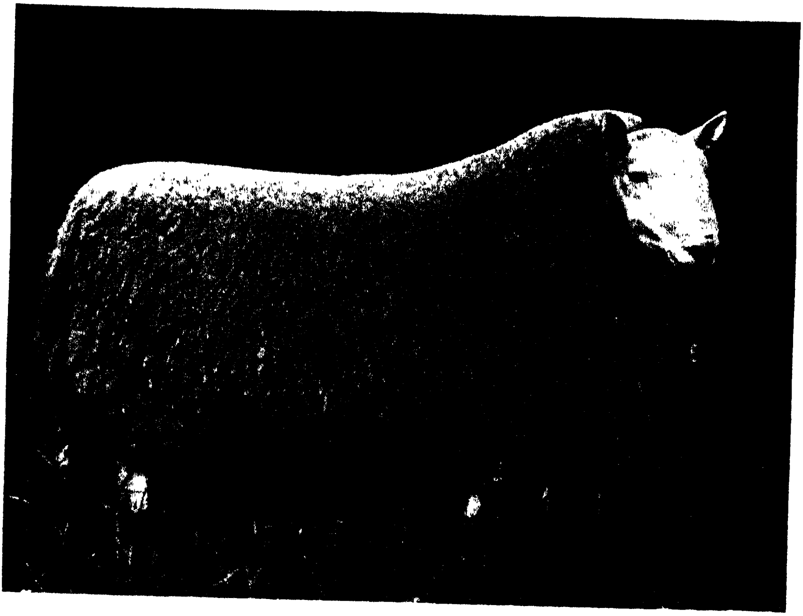
B. Ryeland Shearling Ram

Farmer and Stockbreeder

A. Scotch Blackface Shearling Ram

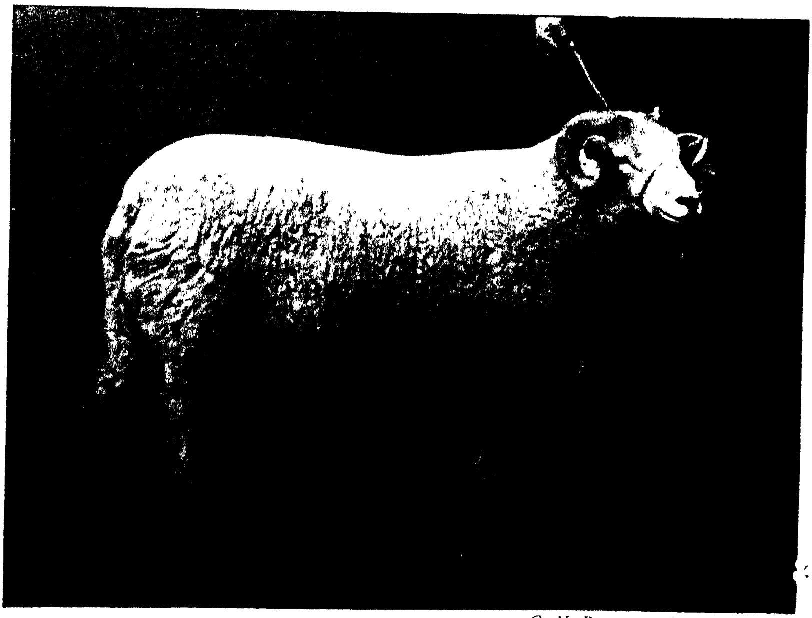
Farmer and Stockbreeder

B. Swaledale Ram



C. Reid, Wishaw

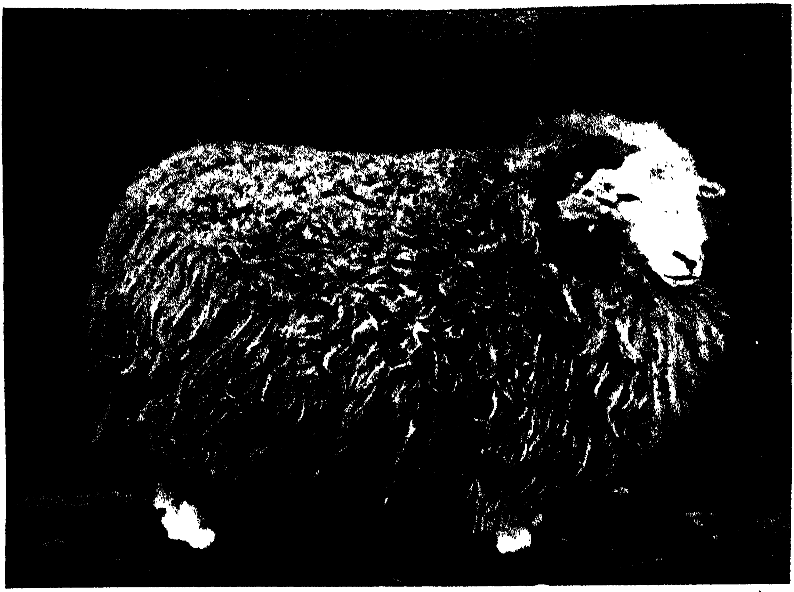
A. SHEARLING CHEVIOT RAM



G. H. Parsons, Alsager, Cheshire

B. WELSH MOUNTAIN RAM

PLATE LIV



Alex. Booth, Hensingham

A. Herdwick Ram

Farmer and Stockbreeder

B. Exmoor Shearling Ewes

in the north *hoggs* or *hoggets* and in the south *tegs*. The sex is also denoted, males being known as tup or ram lambs, tup hoggs, ram tegs; castrated males as wether or wedder lambs, wedder hoggs, etc.; and females as ewe lambs, etc. In some districts the term *chilver* is used instead of ewe lamb. After shearing we denote the males as shearling rams or tups and shearling wedders respectively. The terms *diamond tup* and *dinmont* are also applied at this age. The female at shearing becomes a *gimmer* (north) or *theave* (south). Thereafter we have two-shear rams, wedders, or ewes. Ewes may also be distinguished according to the number of crops of lambs they have borne, as two-crop, three-crop, etc., the first lamb being borne at two years old. In some districts it is customary to denote age by the teeth, as two-tooth, four-tooth, etc., but these terms are less satisfactory on account of the variation in dentition according to breed and environment.[1]

The average period of gestation in sheep is about 147 days, varying a day or two with the breed. The ordinary practice is to complete preparations for lambing about a week before the elapse of five calendar months from the time of turning out the ram. Females are normally mated for the first time as gimmers, to lamb at two years old. Hoggs in good condition will frequently take the ram at an age of seven or eight months, and will then lamb at little over a year; but breeding so early is unprofitable unless the food conditions are really good. As it is rare for more than 70 per cent. of the hoggs to conceive, and as these are apt to suffer in their development, the practice is comparatively rare, and is only to be recommended with well-grown sheep under favourable conditions. The only region where it is common is the Welsh Border. In-lamb tegs should receive specially liberal feeding during the last month of pregnancy. Mountain gimmers, if they are small and ill-nourished, are sometimes given an extra year to develop, lambing for the first time at three. Ram lambs, especially those of the quicker growing breeds like Hampshires, Oxfords, etc., are often used for breeding at seven months old or little more. They should, however, be allotted a smaller number of ewes than old sheep, generally not more than thirty

[1] In sheep the permanent incisor teeth usually erupt as follows, though heavily fed lowland sheep get their teeth earlier, and mountain sheep later:—

First (central)	12 to 15 months
Second	18 ,, 21 ,,
Third	24 ,, 27 ,,
Fourth	33 ,, 36 ,,

or forty. Shearlings and older rams, so long as they remain active, may have from forty to fifty ewes under mountain conditions, and from sixty to eighty when the flock is in enclosed fields. Where it is desired to make the fullest use of a specially good ram, the ewes, as they come in heat, are taken one by one to the ram for a single service. A "chaser" ram is employed to seek out the ewes that are in season. A piece of sacking is tied round the chaser's middle to prevent him from serving.

The time of mating is limited in part by the time of occurrence of heat in the ewe. Thus Dorset Horns will frequently take the ram in May, Dorset Downs and Hampshires as early as June or July, while mountain ewes rarely come in heat till late September or even well on in October. In most breeds the onset of œstrus is governed mainly by the hours of daylight—*i.e.* the ewe begins to come in season with the shortening day. The control of the cycle is by the pituitary body, and it is possible, by injecting pituitary extracts, to make ewes breed at any season. Apart from this the time of mating is fixed by the breeder in accordance with the average climatic and food conditions prevailing in spring. Thus in the south of England, on arable farms, lambing may begin in December or occasionally earlier, while on Highland grazings it does not commence till late in April. The customary dates for turning out rams in various flocks are usually closely adhered to from year to year, and vary from the end of July (early Hampshires) to mid-September (Lincolns), mid-October (Half-breds), 10th November (average Mountain Cheviots), and 22nd November (Blackface Mountain). Rams are left in the flock for about six weeks, which is ordinarily long enough to ensure that practically all the ewes will conceive. The period of œstrus in the ewe lasts about twenty-seven hours and recurs, if she does not conceive, after about sixteen days. A six-weeks' breeding season thus covers at least two and, in a majority of cases, three œstrous periods. In lowland flocks, where the ewes will have close attention at lambing, it is necessary to record the dates of service. To this end the ram is smeared between his forelegs with colouring matter so that he leaves a mark on each ewe that he serves. At the end of, say, each week, the ewes that have taken the ram are given a distinguishing mark, which remains till spring as an indication of the date of lambing. At the end of sixteen days the colour on the ram is changed to a darker one, so that ewes not holding to the first service can be immediately known by the fact that they

are marked with two colours. Any such should be examined, and if necessary, clipped about the tail and inside of the thighs. The longer-wooled breeds are generally so clipped before tupping begins. Occasional ewes that have failed to hold to the first service should be placed with another ram in case the second service should also have proved ineffective. If many ewes are being twice marked another ram should be procured; in large flocks it is best to run two or three rams together with a combined allotment of ewes, as the accident of one ram proving infertile will then cause comparatively little loss. If, however, the rams fight, this plan must be abandoned; also, the method is not applicable in pure-bred flocks, where matings are made with close regard to individual merits and faults. Under ordinarily good conditions and on low ground the proportion of barren or "eild" ewes should not exceed 1 or at most 2 per cent., in hill flocks it may reach 3 or 4 per cent. in ordinary seasons.

The number of twins, or at least of double conceptions, depends partly on the inherent fecundity of the ewes and partly on their treatment before and during the mating season. The smallest number of lambs will be obtained when the ewes are lean and weak, or very fat, or are going back in condition. The highest birth-rate, on the other hand, is obtained if the ewes at mating time are in moderately lean but rapidly improving condition. This is assured—if the sheep have been in low condition after the previous weaning—by bringing them on slowly till within a week or two of tupping, and then by "flushing" on rape, young seeds, or other fresh nutritious food. "Flushing" causes an increased proportion of the ewes to breed early, *i.e.* at the season when there is the greatest chance of multiple ovulations. Failing a supply of fresh green food the ewes may be given up to a pound per head of concentrate daily, avoiding specially fattening materials. Oats are very suitable. The proportion of multiple ovulations (*i.e.* of heats at which two or more eggs are produced) is highest in the earlier part of the breeding season, this explaining the well-known fact that more twins are usually born at the beginning than at the end of the lambing season. Delay in mating after the time when the ewes would begin to take the ram will thus reduce the proportion of twin births. Sometimes twins are not wanted—as, for example, in mountain flocks; ram breeders, too, if they sell their output as lambs, do not want a high proportion, as a good single ram lamb is often worth more than a pair of moderate

twins. Even in ordinary commercial flocks there is often a limit to the number of twins desired—*e.g.* on account of a limited amount of good pasture—and in such cases heavy flushing is only resorted to in years when the ewes are obviously backward. Draft ewes, which are usually sold off the hill in autumn, to be kept for a further one or two years under lowland conditions, will generally be wanted in lamb earlier than the normal time, and must be brought forward in condition more rapidly than the rest. To this end their lambs are often weaned earlier than those of the other ewes. Rams often require special attention during the breeding season. Longwool or other lowland rams put out among mountain ewes must receive a feed of concentrates once a day at least, otherwise they will very rapidly become reduced in condition.

In countries where the winter is very severe, such as the northern United States and Canada, breeding ewes are housed in cool barns during winter, going out for exercise only. In this country they are always wintered out of doors. Ewes of the hardier mountain breeds are left on their usual pastures, being gathered to the lower and sheltered areas only at the prospect of snowstorms. Generally they are made to live without hand-feeding unless or until they are in rather severe straits, which is only in the wildest weather, or when the ground is covered with hard-frozen snow. When given hay unnecessarily they tend to stop foraging for themselves, and since the supply of hay on hill farms is necessarily very limited, they are then in worse plight than if they had been left alone. This is particularly true if feeding is done during the early part of the winter. Instead of relying on hay to a large extent the hill shepherd endeavours to save the lower areas of the pasture during late summer and autumn, so that he has a reserve of natural herbage for winter food. Weak ewes, however, must be taken in from the hill and kept in enclosures near the homestead, where they can receive whatever special attention or feeding is necessary. On lowland pasture-farms the sheep may run on grass without any additional food during the early part of the winter. Later on they are given up to 2 or 3 lb. of hay, according to the condition of the pasture, and sometimes, from a month before lambing, a moderate ration of cake and corn.

On arable or semi-arable sheep farms the winter management varies greatly according to breed, the amount of roots, etc., available, and the time of lambing. Half-bred ewes in the north,

due to lamb in March and April, are usually run on grass without extra feeding until towards Christmas. As the pasture gets bare they are given a limited ration of turnips, say ½ ton per hundred ewes per day, or 11 lb. apiece. Later they will generally be folded on turnips for half the day, or overnight, returning to the pastures at other times and receiving perhaps a little hay in addition. When roots are abundant ewes are sometimes folded permanently on the crop; but the method is not always satisfactory, the ewes, though they may keep fat, getting into a soft and unhealthy condition. In any case they should be put back on pasture, with a restricted root ration and some hay, a few weeks before lambing is due to begin; they also benefit by daily exercise, such as may be given by driving the flock daily to and from an outlying field. A light daily ration of concentrates will be given from a month before lambing in order to bring the ewes into good condition for milking. In some districts chaffed oat sheaves, straw and grain together, are fed in lieu of hay and concentrate. In March, just previous to lambing, the ration might be: turnips, 20 lb.; oats, peas, dried grains, 1 lb.; hay, ½ lb.—varying, the hay particularly, according to the amount of rough herbage on the pasture fields. Draft ewes in the lower districts, that are due to lamb perhaps a month earlier, and are to be fattened along with their lambs, are given somewhat more liberal treatment.

In the south on those few farms where folding is still practised a common succession of winter foods is: (1) turnips, (2) swedes and marrow-stem kale grown in alternate strips, (3) swedes and thousand-headed kale, and (4) swedes. Folding is done for a longer period and more regularly. A few mangolds are often valuable, after lambing, in tiding over the flock until "seeds" or other summer food is available. Clover, lucerne, or sainfoin hay, or pea haulm, may replace the seeds hay of the north. The aim is, however, the same, viz. to keep down costs during the early stages of pregnancy and, by adding concentrates later, to ensure strong lambs and a plentiful flow of milk. In one series of experiments it was found that half-bred ewes which gained 20 lb. of live weight during their period of pregnancy produced quite as large and as vigorous lambs as others which were more heavily fed and gained 50 lb. in weight. On the other hand, a third group which were more poorly fed, so that they barely maintained their weight, produced a large proportion of very weak lambs, many of which could not suck.

On sheep farms where the arable land is heavy, as, for example, in many districts of Northumberland, folding in winter is impossible. In such cases the root crop is stored in autumn and the daily allowance is thrown out to the ewes on grass.

Before lambing, the ewe flock should be collected and looked over to see that the teats are clear of wool, otherwise the lambs will be liable to seize and swallow locks of wool in their attempts to suck. Gimmers (theaves) often have to have a considerable amount of wool removed. The operation is known as " udder-locking."

Lambing, in hill flocks, goes on in the open, and generally on the mountains, though in some cases the ewes are brought down to lower enclosed pastures. It generally begins in the second or third week of April and continues throughout the greater part of May. Each shepherd, who will have a "hirsel" of perhaps twenty-five or thirty score of lambing ewes under his charge, is given a temporary assistant (or at least a half share of the time of such an assistant) for the busy and critical period of four or five weeks. This arrangement makes it possible for the sheep to be seen at least two or three times a day, and will generally ensure that assistance is available in cases of difficult or protracted labour. The chief causes of heavy mortality are snow or heavy rainstorms; in the first case the lambs may be buried, or simply exhausted by the cold and the heavy going; in the latter they are very liable to be drowned in attempting to follow their dams over swollen torrents. In bad weather the sheep are gathered into the naturally sheltered areas on the lower ground. Even in good lambing seasons weak ewes and those with weak lambs require to be brought down and fed, but the main part of the flock should be made to travel the ground in a regular way. The natural habit of hill sheep is to spend the night on the hill-tops, to move down to the valleys in the morning and up again in the afternoon, grazing as they go. When the lambs are young, however—and especially if the ewes are in low condition—many will tend to lag behind and to remain on the lower ground, which would then soon become foul with droppings; very heavy worm infestation may result. Hence the shepherd must see that all that are able do actually go up the heights in the evening, and this often entails heavy work. The earliest herbage on mountain grazings is the " Draw Moss " (sheathing cotton-sedge or cotton grass), *Eriophorum vaginatum* which grows on marshy land. On grazings where this is not abundant, care must be taken to preserve it by avoiding over-

drainage, and the sheep should have full access to the marshy areas in early spring.

A considerable part of our mountain grazing in Scotland and Northern Ireland is infested with sheep ticks (*Ixodes ricinus*) which carry two specific diseases (Louping-ill and tick-borne fever) and also cause loss by producing abscesses and blood poisoning (pyæmia) in young lambs. The ticks are most common on coarse, dense-bottomed herbage where the humidity is high; hence any treatment that will promote a finer sward and reduce humidity will help to control the pest. Drainage, the employment of cattle to eat off the coarse stuff, and burning are all helpful, while repeated dipping of the sheep tends to kill off the parasites. Lambs are most susceptible to tick-borne disease, and it is best to try to protect them. Dusting them with an insect-powder, such as derris or a preparation of D.D.T., is easier than dipping and gives about four weeks' protection.

Considerable areas of hill-grazing from Bodmin Moor in Cornwall to the north of Scotland are deficient in cobalt. Cobalt deficiency leads to reduced numbers of lambs, which make very poor growth. The areas in question have been recognized in the past as "pining" land, but the condition has been diagnosed only in recent years. Good results have been obtained by applying cobalt sulphate, at the rate of 2 lb. per acre, to the pastures and also by providing salt licks containing cobalt. The more certain preventive is to drench the ewes in autumn with 200 to 400 mg. of cobalt, and to drench the lambs in spring and again in summer.

Ewes on mixed farms will have been classified in autumn into five groups according to the period (week) in which they are expected to lamb. Each batch in succession, as it comes due to lamb, is removed to the lambing field, which should be a good dry pasture with the best available natural shelter. Artificial wind-breaks, consisting of thatched hurdles or sheep-nets stuffed with straw, and set up in the form of a cross, should be placed here and there. In or near the lambing field should be a lambing shed with a hut in which the shepherd and lambing man spend alternate nights. The shed is usually a permanent structure; some farmers prefer temporary shelters on the ground that they are less liable to harbour disease, but permanent erections, if they receive a thorough annual disinfection, are not open to serious objection. The shed consists of a series of pens, about 4½ or 5 ft. square, with a low roof and arranged to form a hollow square

(Fig. 38). In ordinary cases the central yard is open, but for valuable pure-bred flocks the whole may be roofed in. In any case, the shed should be on dry ground with a sheltered situation and a southern exposure.

During the day the ewes go out in the lambing field; at night they are confined in the central yard of the lambing shed, which should be well littered with dry straw. Ewes lambing at night are placed one in each small pen. Assistance in lambing should not be given too soon, and the assistant should thoroughly disinfect

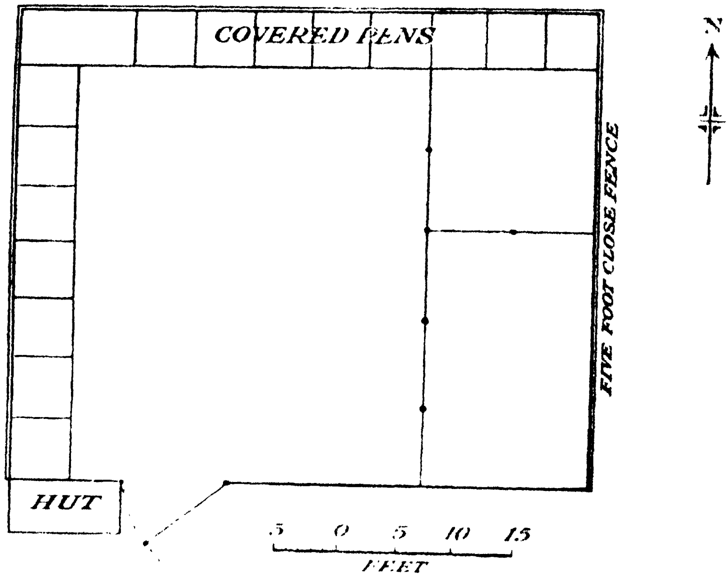


Fig. 38.—Lambing Pen for Flock of 300 Ewes

his hands before and after each case. Each ewe and her lamb or lambs may be given a distinguishing dot of colour, in order to avoid any possibility of subsequent confusion; but as a ewe generally keeps in touch with one of her lambs it is often considered sufficient to mark the twins. Generally there will be a proportion of triple births, as well as a few orphan lambs. On the other hand, there will be many singles and a few ewes whose lambs die. There should be a reassortment, by transferring lambs, so that the flock is made to consist entirely of singles and doubles. In cases where a lamb has died its skin should be tied over the back of the stranger, when the latter will generally be adopted at once. Other

devices, such as that of rubbing the ewe's nose in whisky to deprive her temporarily of her sense of smell, are successful in other cases. Refractory ewes may have to be tied up by the neck for a few days in order to prevent maltreatment of foster lambs. In any case, reassorted families must be kept penned together until it is seen that they have settled down. Gimmers (theaves) should not be given second lambs if ewes are available.

The ewes and young lambs are kept in the more sheltered fields near the centre of operations for a week or two, and are then put out in lots to the ordinary pastures. On enclosed farms the flock will be split up into lots of similar age, etc., gimmers with double lambs being given the best grass, ewes with singles the worst. Feeding with roots, hay, and concentrate must be continued until grass or a forage crop becomes available. This may be as early as mid-April in the south, often after mid-May in the north. When grass becomes plentiful, roots and hay are withdrawn, and the concentrate is either withheld or is transferred from the ewes to the lambs. Soon after lambing is completed the lambs are docked, males not required for breeding are castrated, and ear-marking with the flock mark may be done—although it may be postponed until after weaning. In pedigree flocks the sheep are given individual ear tags or are tattooed in the ear with individual numbers. In hill flocks the "gathering" is taken as an opportunity of enumerating. In mountain sheep the tail is often left long (for protection), but all lambs that are likely at a later stage to receive roots or concentrates are better docked. Males that cannot be castrated ("chasers" or "rigs") have the tail left long as a distinguishing mark.

Lambing percentages vary greatly with conditions. Mountain flocks in normal years may give from 60 to 120 lambs per 100 ewes—less on the poorer and higher ground, more on the lower and better sort of grazings. In years of storm and flood the increase may be as low as forty or fifty, and occasionally the ewe lambs will barely be numerous enough to replace losses in the older sheep. Probably the average of lowland flocks all over the country is about 130 per cent., and the most prolific flocks reach an average, over series of years, of about 160.

In the north and west, sheep are generally kept on pasture throughout the summer. In the south and south-east, especially on the Chalk and Oölite formations (semi-upland and rather poor arable), the traditional practice (now, however, becoming much

less common) is to run the ewes on Down pasture, if this forms part of the holding, during only part of the day; for the rest the flock is folded on forage crops—rye, trifolium, and winter vetches in spring; clover, sainfoin, lucerne, spring vetches, mustard, and rape in summer; rape, mustard, kale, and turnips in autumn. The folding system is, of course, expensive in labour as compared with ordinary grazing, and on this account has declined very greatly during the past forty years; but it permits the keeping of a considerably larger head of stock than would otherwise be possible, particularly on the drier sort of land where pasture is not very productive.

The stocking of pastures so as to get the best results can only be decided by trial. The best seeds pastures will carry three ewes with double lambs per acre; ordinary pasture perhaps two ewes (with, say, three lambs) per acre; good grassy hill land about one per acre, and the poorer sorts of mountain land as little as one ewe to 5 or even 15 acres. On the best permanent grass it may be wise to put on no more than two ewes and their lambs to the acre and to complete the stocking with cattle; heavier stocking with sheep tends to increase the incidence of internal parasites, such as stomach worms. Most mountain grazings have a recognized carrying capacity which, however, can be improved by treatment, *e.g.* by application of lime and phosphates. In most cases it is, of course, economically unsound to manure the whole area of the grazing, but highly beneficial results may be obtained from dressing quite small areas of the better land. The sheep are then able to adjust their mineral balance and make much improved growth. The direct feeding of mineral mixtures (ground limestone, steamed bone flour, and common salt) is beneficial on hill grazings that are very deficient in minerals. Common salt should be provided in all cases; this can most conveniently be done by placing large lumps of rock salt under simple shelters.

Most sheep pastures are improved by the addition of a small number of cattle—say one young store bullock to every five or ten ewes. Such cattle cannot be expected to fatten, as the sheep are continually eating out the finest of the herbage; but they make quite satisfactory growth, and keep the grasses from becoming coarse and from running to seed.

Of the various special incidents of the summer season, shearing is the first. In the south this is done as early as the beginning of

May; in north-country low-ground flocks about the beginning of June, and in the highest mountain grazings as late as the first or second week of July. The date is determined mainly by the time of the natural "rise" of the wool, which becomes apparent a few weeks after the return, with the spring, of a vigorous thriving condition. The time occupied in clipping depends on the type of wool that the sheep carries. With Shortwools, less than a score will represent a day's work for a good hand-shearer, while with Blackfaces, where an inch of wool or more is left on, fully five scores per day can be shorn. In wool-producing countries like Australia, where sheep-shearing is a specialized occupation, and power-driven machines are generally used, the number clipped in relation to the quality of the work is far greater. Machine-shearing is now normal practice in the larger British flocks. Sheep may either be washed in clean stream water a week before clipping, or may be shorn in the grease. There is a loss of weight, generally from 10 to 20 per cent., if washing is done thoroughly, but the washed wool brings a proportionately higher price. Washed wools can be more accurately valued by buyers, and hence the washing may often be profitable.

The time for summer dipping is generally about three weeks after clipping, when there is just wool enough to carry the dip. Summer dipping has the double object of killing external parasites (keds, ticks, scab-mites, lice), and of warding off attacks of blowfly. The type of dip formerly used, based usually upon sodium arsenite and sulphur, has been replaced by a material containing usually both D.D.T. and benzene hexachloride (Gammexane) with sometimes arsenical compounds as well. The great advantage of the new insecticides is that they give protection against blowfly, and against reinfestation by skin parasites, for a much longer period than the older materials—generally for a period of about six weeks. In the use of all dips it is important to observe the directions of the makers; some shepherds tend to use stronger solutions than those recommended. Ewes and lambs are generally dipped at the same time. If it should be found necessary to dip a breeding flock when the lambs are very young it is essential to work with very small lots of sheep, otherwise the ewe and her lamb may fail to recognize each other after the operation. Reference has already been made to dusting lambs as a means of preventing infestation with ticks.

During July and August shepherds must be continually on the outlook for sheep that have been "struck" by the fly, and the affected parts must be dressed as early as possible. The most successful preventive treatment so far discovered is dipping or spraying with a preparation of D.D.T. Spraying, as compared with dipping, makes for great economies both in time and materials. It requires special apparatus which, however, is easily portable, so that the operation in small flocks might be done on contract. Apart from preventive dipping or spraying, the clipping off of locks of dirty wool from about the hind quarters is important, as the fly is attracted by smell. Dip that is heavily contaminated with fæces is worse than useless as a fly deterrent, so that the bath must be frequently emptied and refilled with clean material.

Lambs on pasture are very liable to infestation with a variety of stomach-worms and it has been a routine practice, in many flocks, to drench them with a weak solution (1 per cent.) of copper sulphate. This is effective against the commonest species (*Haemonchus contortus*), but in other cases it has been necessary in the past to use either a drench of copper and nicotine sulphates or arsenical preparations. The drug phenothiazine is very effective against most of the common stomach and intestinal worms except the very common twisted stomach-worm (*Haemonchus*). Where lambs show symptoms of heavy worm infestation—poor general condition, scouring, and anæmia—it is well to have the droppings examined in order to determine the species of worms concerned. The most appropriate treatment will depend on the prevalent species. One method of administering phenothiazine is to make up a mineral lick with about 7 per cent. of the material, so that the sheep may dose themselves.

Weaning is generally done when the lambs are from three to four months old, *i.e.* between May and August, according to the date of lambing. At weaning the ewes are put out to the poorest and barest pastures, in order that the flow of milk may be dried off, while the lambs are given the best and cleanest grass available, fields having generally been rested for the purpose; or they are folded on fresh forage crops. Clover aftermaths are ideal for the purpose, only in this case the herbage must be dry when the lambs are turned on, otherwise many of them may get hoven (bloat). Most store lambs are disposed of by the breeders at large sales, which commence in June, July, or August, according to the

district; at the same time, or generally a little later, the breeder buys in ewe lambs to replenish his breeding flock, unless a proportion of the home-bred lambs is being retained for the purpose.

Draft and cull ewes are disposed of at other special sales in July, August, or September. On most arable farms, and on the better mountain grazings, ewes are kept in the breeding flock until they are of a certain definite age. This is generally four and a half years (four-shear or three-crop), but sometimes a year more. On the poorer mountain grazings, where sheep have a special value when acclimatized[1] and accustomed to the ground, there is no definite age for drafting, but each ewe is retained in the flock so long as she remains active and healthy. Even in flocks where ewes are drafted out at a fixed age, the younger ewes must be looked over and unhealthy animals, bad milkers, and ewes with defective teeth or udders culled out. Draft ewes are brought in to good pasture, or folded on forage crops, as soon as the flow of milk has ceased, and are brought forward rapidly so that they may be in good condition for early tupping. Generally, the draft lot is examined and culled, so that the major part may be sold as fully guaranteed, *i.e.* certified correct in udders and mouths. A second lot will be made of those that are broken-mouthed but otherwise correct, while unhealthy animals or those with defective udders, etc., are sold separately for fattening.

Hill ewes after weaning and until, say, October, are herded on to the higher parts of the grazing in order to conserve the lower areas for winter use. Lambs that are not sold at weaning time are allowed to rejoin the flock after about ten days, by which time the ewes' flow of milk will have ceased.

In autumn sheep must be kept off marshy ground, water meadows, etc., as otherwise they are liable to pick up large numbers of liver-fluke larvæ. When it seems likely that infestation has occurred, the sheep should be treated two or three times, at monthly intervals, commencing in September with male fern or ethyl hexachloride. On wet grazings this may be a matter of routine.

Winter dipping is done during spells of good weather in

[1] There is good reason for the belief that the main factor in acclimatization is that the stock has been mildly attacked by (and has built up immunity from) louping-ill and tick-borne fever. Immunity to the former disease can now be conferred artificially. As mentioned on page 695, both diseases are carried by the tick *Ixodes ricinus*, which also causes septic infections (pyæmia) in young lambs.

autumn, generally in October, but either before the commencement or after the close of the tupping season.[1]

Besides skin parasites, maggots, and liver-flukes, all mentioned above, there are many diseases and parasites of sheep that must be guarded against. Foot-rot is common in most breeds when they are kept on wet land. The ordinary preventive is to walk the flock through a foot-bath containing 1½ in. of a disinfectant and astringent solution, any actual cases having been treated in advance. Recent work suggests that the usual "walk-through" foot-bath is not very effective. It is better to place the solution in a relatively large shallow bath and let each batch of sheep stand in it for perhaps half an hour. A suitable material is a 2 per cent. solution of white arsenic dissolved by boiling with alkali. An alternative material with better powers of adhesion is 4 per cent. creosote in crude oil. The solution should not touch the skin, and sheep that fall in the bath must be carefully washed. The foot-bath must be covered and padlocked when not in use.

Garget or udder clap, inflammation of the womb after lambing, scour in lambs, lung-worms and tape-worms, lamb dysentery (which can now be prevented either by vaccinating the ewes or by injecting the lambs with serum), sturdy, louping-ill or trembling and braxy (which can be prevented by vaccination), scrapie, tick-borne fever, pulpy kidney, and several other troubles are often responsible for serious loss. In each case the flockmaster must endeavour to avoid such loss by general good management as well as by special preventive measures.

Sheep often get all the water they require from plant sap, rain, and dew, and under such circumstances do not drink; but in spells of dry weather they do so freely, and water should be offered in all cases of doubt.

Ewe lambs for breeding may be selected from home-bred stock if this be kept pure; indeed, on the poorer mountain grazings, home-bred sheep are much more likely to survive than others introduced. On the other hand, breeders who produce cross-bred lambs for the butcher should obtain ewe lambs from others who specialize in the breeding of such. In either case the animals

[1] In certain parts of the country there are Government regulations requiring dipping to be done at least twice a year, and between certain specified dates. Sheep moved from an area which is scheduled for scab into a "clean" area are required to be dipped twice, the second dipping being between eight and fourteen days after the first. There were good grounds for hope, at the time of writing, that sheep-scab had been completely eradicated.

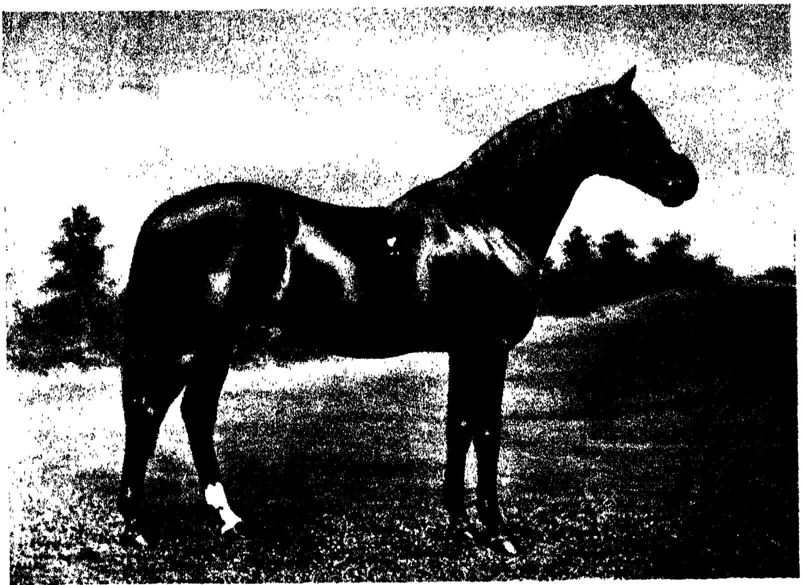
should be selected carefully and individually, and the number bought or retained may well be 10 or 20 per cent. greater than actual requirements, in order to allow for subsequent culling. Hoggs intended for the breeding flock should be so wintered as to keep them in healthy growing condition, but should not be made fat. Those from mountain grazings have generally to be wintered on low ground, and those from extensive mountain districts like the Scottish Highlands have sometimes to travel a hundred miles or more for wintering. Such are, almost invariably, wintered on grass alone, even if this means that they become rather reduced in condition. Root feeding is undesirable because after such artificial treatment the sheep do not take kindly to their native hillsides. Ewe hoggs on arable or semi-arable farms may run on grass until well on in the autumn, when they are folded on roots for a gradually increasing period of the day. Later on, in January, or earlier or later according to the time of commencement of root feeding, the temporary incisor teeth begin to break off, so that roots must thereafter be fingered and fed in boxes. An allowance of 16 lb. of roots (hardy yellow turnips or swedes) and ¾ lb. of hay will suffice for those of ordinary size (about 100 lb. live weight). If such materials are not available in sufficient quantities, the bulkier concentrates such as dried grains, sugar-beet pulp, and oats may be used, mixed with a little chaffed oat straw or pea haulm. As soon as grass is available the hoggs will go out on the poorer and higher fields, the better pastures being, of course, reserved for the ewes. They will be shorn a week or ten days before the milking ewes, because the wool "rises" earlier. They join the ewe flock generally some weeks before the mating season, or when the old ewes are drafted out. In some flocks the gimmers (theaves) are not put to the ram until two or three weeks after the ewes, the object being to secure better weather and food conditions at their lambing time. In some mountain flocks the gimmers as well as the hoggs are "wintered away."

Fattening.—Lambs of the earlier-maturing breeds can be brought to slaughter weight and condition as early as ten weeks of age. Under conditions of free markets the most popular carcass weights are probably about 25 lb. for the small hill breeds and 35 to 40 lb. for others. In general (apart from cast ewes) the great majority of animals reach the meat market at ages ranging from three to fifteen months, though occasional lots

of two-year-old and even three-year-old wedders of mountain breeds are still seen.

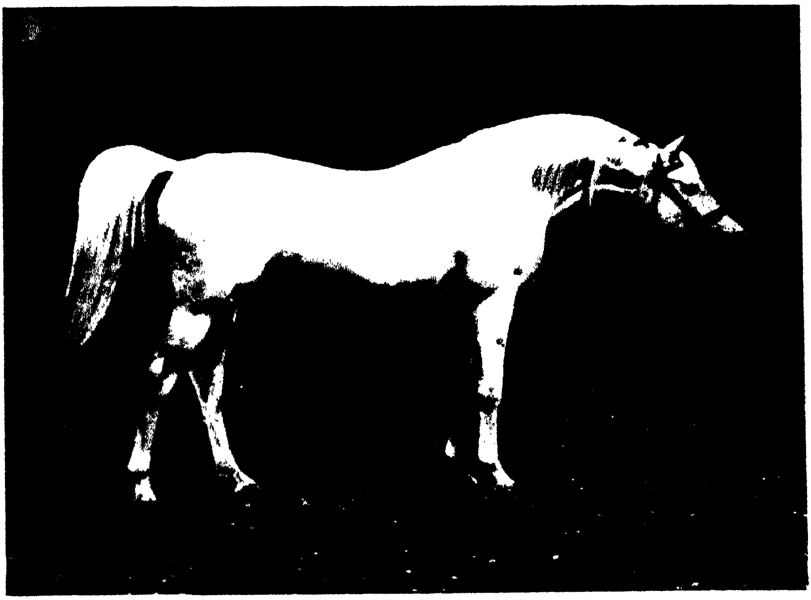
The earliest fat lambs are usually the produce of draft ewes—the latter are purchased by farmers of the better arable land between July and September. Either fully guaranteed ewes or broken-mouthed ones (if they are young) may be bought—the latter being generally cheaper but requiring to have their roots cut during winter. Some are sold already tupped; others will generally be put to the ram without delay. They must have a considerable amount of hand feeding during winter, and concentrates must continue to be offered until the arrival of the "spring flush" of grass. As soon as the lambs will eat they are fed with concentrate, either along with their dams or separately. Separate feeding may be arranged by placing the lamb troughs in an enclosure with "lamb creeps" in the surrounding fence. The "creeps" may consist of special hurdles with apertures that can be adjusted to the size of the lambs and with wooden rollers on the top and sides to avoid any risk of the lambs being caught. The "Creep Feeder"—a covered trough and creep made as a unit—is even more convenient. One drawback of any "creep" arrangement is that a small proportion of the lambs may fail to eat concentrated food, even if this be made attractive by the addition of locust bean or spice. An alternative arrangement is to separate the ewes and lambs at each feeding time by means of a suitable run-way and with the help of a dog. The lambs may at first be left in their enclosure, with food before them, for some time. It is then rare for any to refuse the food offered in the trough.

Traditional lamb foods are complex mixtures containing such materials as linseed cake, bran, broken peas, kibbled or flaked maize, oats, etc., with broken locust-beans to make the mixture palatable. Compounds in the form of "lamb nuts" are, however, more convenient and less wasteful. If folding is practised the lambs are run before the ewes, *i.e.* they are allowed access to the standing crop by means of hurdles through which the ewes cannot pass, the latter following on to clean up. As soon as the lambs are fat (the ewes will generally be fat enough) they are marketed together with their dams. Early lambs of this sort, weighing perhaps 70 to 80 lb. live weight or 35 to 40 lb. carcass, command a high price; but the ewe will often bring less than she cost the previous autumn. Shropshire, Southdown,

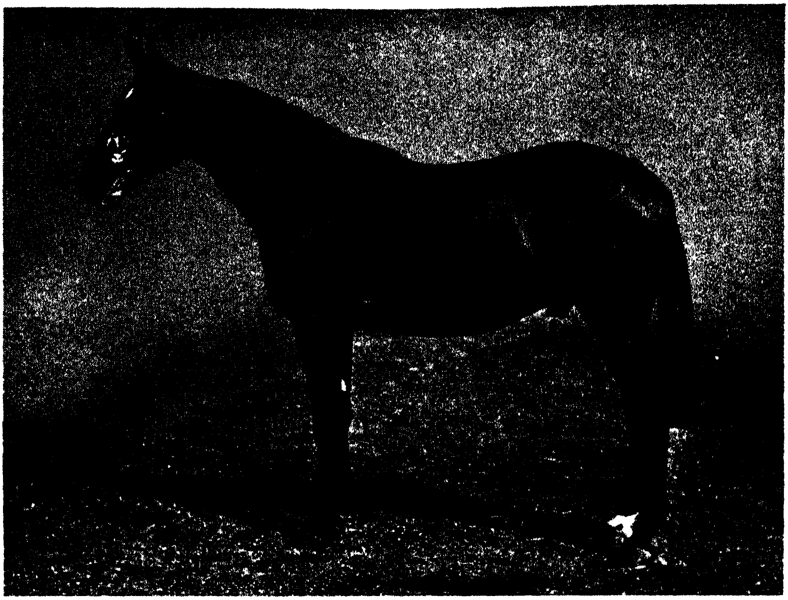


Clarence Hailey, Newmarket

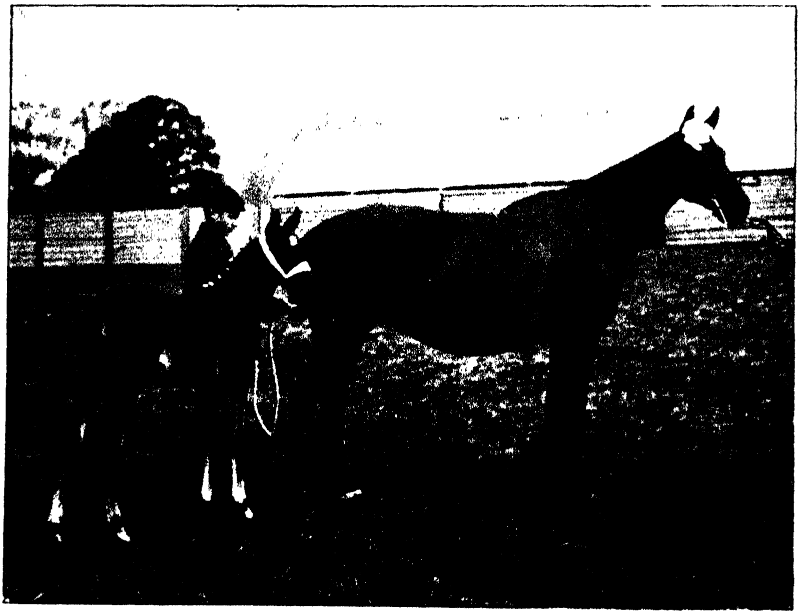
A, Thoroughbred Stallion



B, Arab Stallion



A. Hunter Gelding



G. H. Parsons, Alsager, Cheshire

B. Polo Pony Mare and Foal

Suffolk, and Oxford rams are perhaps those most widely used for the production of such lambs, but Leicesters and Border Leicesters give good results with Down ewes.

The produce of draft ewes is succeeded on the market by selected single lambs from regular breeding flocks on the better arable farms, and by July and August lambs of many breeds, not excluding pure-bred Blackfaced Mountain, will be found on the fat markets. In all such cases there will have been no store period—the processes of rearing and fattening having been combined. Later on there come lambs that have been reared as stores, weaned, very frequently sold by breeder to feeder, and finished off by the latter. The most forward of these, weighing perhaps 80 lb. or more at four months old, will be fattened, in a period of a few weeks, on clover aftermaths, rape, or other forage crops, receiving about 1 lb. per day of nutritious concentrate; they make rapid gains, as high as 4 or 5 lb. weekly. Hampshires, Oxfords, and crosses of these with Longwool and Half-bred ewes, are the favourite types for this system. Less forward lambs, including those of many mountain breeds, may be very well finished on rape or rape and rye-grass mixtures.

Lambs for "hogging" are carried on as stores, first on grass or forage crops and later on roots, until they are considered sufficiently grown to be fattened. Their general treatment meanwhile will be the same as that of ewe tegs for breeding. In most markets, under normal peace conditions, a fat live weight of not more than 120 or 130 lb. should be aimed at, even if the sheep are capable of reaching far greater size. Heavy sheep give joints that are too large for modern taste, and bring a lower price per pound. Moreover, live-weight increase becomes more expensive as the limit of growth is approached. There is also a desirable pitch of fatness beyond which it is easy to go with the fatter breeds like Oxfords and Leicesters. Lambs and young tegs are rarely too fat—the difficulty is usually to get them fat enough—but large fat carcasses, especially during spring and summer, are generally in poor demand. As a rule, therefore, tegs are kept as stores, and as cheaply as possible, until they weigh from 60 to 90 lb., according to breed, and are then put up for fattening—the latter process occupying from two to four months. The following are examples of winter fattening rations, based on a live weight of 100 lb. (which is actually a rough average weight for fattening tegs), and each supplying about 2¾ lb. of dry matter, about 1·6 lb.

starch equivalent, and 0·25 lb. protein equivalent. On such rations a live-weight increase of about ¼ lb. per day, or rather less than 2 lb. per week, may be expected. It appears that the most uniformly satisfactory results are obtained on rations with this sort of balance, *i.e.* a ratio between protein equivalent and starch equivalent of about 1 : 6 or 7. Probably it is desirable to commence with the narrower ratio, because in the earlier part of the winter the sheep will still be in fairly rapid growth. Later the ratio may be widened to 1 : 8 without harm.

	Dry Matter.	Starch Equivalent.	Protein Equivalent.
(1) 14·0 lb. swedes	1·61	0·98	0·098
0·5 ,, clover hay	0·42	0·16	0·035
0·25 ,, distillers' dried grains	0·23	0·14	0·048
0·25 ,, Egyptian cotton cake	0·22	0·11	0·042
0·25 ,, flaked maize	0·22	0·21	0·022
Totals	2·70	1·60	0·245

	Dry Matter.	Starch Equivalent.	Protein Equivalent.
(2) 16·0 lb. soft yellow turnips	1·36	0·80	0·064
0·75 ,, seeds hay (clover)	0·63	0·24	0·045
0·50 ,, flaked maize	0·44	0·42	0·043
0·25 ,, decorticated earth-nut cake	0·22	0·18	0·102
Totals	2·65	1·64	0·254
(3) 10·0 lb. mangolds	1·32	0·70	0·040
0·75 ,, clover hay	0·63	0·24	0·052
0·50 ,, oats	0·43	0·30	0·038
0·50 ,, linseed cake	0·44	0·38	0·125
Totals	2·82	1·62	0·255

Larger gains, up to 2·5 or 3 lb. per week, may be obtained with the larger breeds of sheep by reducing the amount of hay to ¼ lb. and giving a correspondingly larger allowance of concentrates. In some districts hay is omitted altogether without any apparent detriment to the health of the sheep.

Lambs of mountain breeds, and crosses such as Mashams and Mules (Greyfaces), may be wintered on grassland with little or no hand feeding and fattened on grass during the ensuing spring and early summer. This, naturally, is most successful when no breeding flock is maintained, the pastures being stocked in late summer with cattle only; the object being to leave a good "bite" for the winter and to avoid trouble from internal parasites. The rate of stocking in winter must, of course, be

fairly low. The same practice is feasible with lowland breeds and crosses, but the sheep, at perhaps fifteen months old, are much beyond the size desired by consumers.

Apart from questions of available supplies of feeding stuffs, the following points require attention in rationing: In the early part of the winter feeding season—October and November—roots are liable to cause scouring and other disorders. The change from grass or summer forage crops to root feeding should therefore be made gradually, and the root ration should at first be limited. Again, if wet weather occurs and the sheep on the root land become obviously uncomfortable, they should be returned to pasture and have the roots conveyed to them. Thirdly, a proportion of the roots should be stored so that there may be no need to feed them in a frozen condition.

The choice of hay is important with feeding sheep. Pure legume hay—red clover or lucerne, for example—is usually freely eaten and is valuable on account of its high protein and mineral content. Even with this, however, unless it has been cut at an early stage of growth, fattening sheep will tend to reject the stemmy portions, and a certain amount of wastage must be permitted if the sheep are to make rapid progress. When mixed hay is fed the animals tend to pick out the clovers and leave the grasses. Grassy hay—meadow or rye-grass—especially if it has been over-ripe when cut, is not liked by sheep, and it is frequently difficult to get fattening tegs to consume more than $\frac{1}{4}$ to $\frac{1}{2}$ lb. unless by severely restricting the other ingredients in their diet. This, in turn, naturally interferes with the rate of progress.

Feeding sheep are occasionally housed in cool airy sheds. Housing may result in a substantially improved live-weight increase if it happens that outdoor conditions are bad. But in dry weather, even if it be very cold, outdoor sheep do quite as well. The common practice on light soils is to fold the sheep on the root land, moving the fold forward as the crop is consumed so that the ground may be evenly manured. When large numbers are being fattened they are best divided into lots of not more than about 200. A man can tend about 250 to 300 fattening tegs where roots have to be cut, and about 100 more if he has help to move the nets, feeding boxes, etc. A small portable engine for driving the root cutter effects a great saving of labour.

In spring and summer, hoggs or wedders of the later-maturing breeds are fattened on grass or forage crops, with or without the

addition of concentrates. Fat sheep may be clipped as much as a month before the normal time for breeding stock.

Hoggs in wool—but with the wool dry and clean, and in fair marketable condition—may yield from 48 to 52 per cent. of their live weight as dressed carcass, the average of market sheep being nearer the former figure than the latter. Newly shorn sheep give about 5 per cent. more. Heavy and very fat wethers may dress up to 65 per cent. or occasionally more.

GOATS

Goats are valued either for their fleeces or their milk. In the first class are the Cashmere and the Angora, of which the latter is by far the more important commercially.

The Angora is native to the province of that name in Asia Minor. It is of a whole white colour, small in size (60 to 100 lb. live weight), and horned in both sexes. The fleece (mohair) varies a good deal in quality, but in the best specimens is extremely fine, silky, and lustrous. Typically it is from 8 to 10 in. long and hangs in separate and well-defined ringlets. Four pounds is an average weight of fleece, but superior specimens shear 6 lb. and occasionally up to 14 lb. Fine mohairs have a distinct use in the manufacture of plushes, velvets, and bright lustre materials, and command a price comparable to that of fine wool. The quantity used annually in the Bradford district runs into thousands of tons. The flesh of the young and fat Angora is said to be good. The breed is not very prolific, twins being rare and the annual increase being generally under 80 per cent. Angoras require a dry climate but are otherwise hardy, and thrive under semi-arid conditions where sheep do not prove a complete success. The chief mohair-producing countries in order of importance are South Africa, Asia Minor, and the United States (western and south-western states).

Milch goats are of several breeds; the best known are the Toggenburg and Saanen (Swiss), the Nubian, and the Maltese. In Britain we have the imported Swiss and Nubian types, as well as somewhat ill-defined sorts like the Anglo-Swiss, Anglo-Nubian, and Anglo-Nubian-Swiss derived from crosses of the foregoing with the native type. Goats' milk is comparable in composition with cows'—somewhat more variable though probably, on the average, rather richer in fat and poorer in other solids. It is often

more easily digested by delicate persons, and has the advantage that it can be reckoned to be free from tubercle bacilli, which are the commonest of the more dangerous organisms found in cows' milk. Does of good type reach yields of 3 to 5 qt. per day and occasionally up to 2 gals. The lactation period is ordinarily five or six months, but may extend to nine or ten. Lactation yields of over 400 gals. have been recorded in ten months, and the average in good recorded herds is over 200 gals. The highest recorded lactation yield up till 1946 was of 5928 lb. of milk in 338 days. Goats, as is well known, will live on almost any sort of herbage, and in mountainous districts, or wherever food is scanty, they form a valuable source of milk. It seems unlikely, however, that they will ever become commercially important in lowland districts where improved dairy cattle can be kept.

CHAPTER VI

HORSES

THE horse family (Equidæ) forms part of the group of Perissodactyla, or odd-toed ungulates. Zoologists include all members of the family, whether horses, asses, or zebras, under the genus Equus.

The Zebras, which are found only in Africa, include the now extinct Quagga (Cape Colony), the True or Mountain Zebra (south-western Africa), Burchell's Zebra (Transvaal, etc.), Grevy's Zebra (Somaliland), and two or three more species or sub-species related to one or other of the foregoing. None of the zebras has attained any importance as a domesticated animal, although specimens of several species have been successfully broken both to harness and the saddle. Grevy's Zebra has generally been regarded as the most promising from the utility point of view.

The Wild Asses embrace two African types, the Somaliland and the Nubian; and two Asiatic, the Onager of Syria, Persia, Arabia, and India, and the Kiang of Turkestan, Mongolia, and Tibet. Domesticated donkeys are generally regarded as of purely African origin, but some authors have supposed that Onager blood has been blended with African in some of the larger breeds.

The only truly wild horse now existing is the *Equus Przevalskii* of the Gobi Desert and north-western Mongolia. Whether or not this wild species has been concerned in the origin of our domesticated horses is somewhat uncertain; that it is not the sole ancestor is fairly generally agreed, most authorities supposing that at least three distinct species are represented among our modern breeds. Although these original species have been crossed and intermingled to a considerable extent, we may still distinguish fairly pure representatives in the Celtic pony (*Equus celticus*) of the Western Isles; the Arab, Barb, etc. (Oriental light-legged type), and the Shire and Belgian (Western heavy-legged type).

Hybrids between horses and zebras, asses and zebras, or horses and asses may be produced with comparative ease. The hybrids, however, with rare and doubtful exceptions, are sterile. Of the hybrids the only one of much economic importance is that between the male donkey or jackass and the mare, viz., the mule.

The opposite cross, between a stallion and a she ass, is of much less value on account of its smaller size.

As a preliminary to a description of the various types of horses some explanation of "points" and gaits is necessary. **The points** are shown and named in Fig. 39. Of the things that go

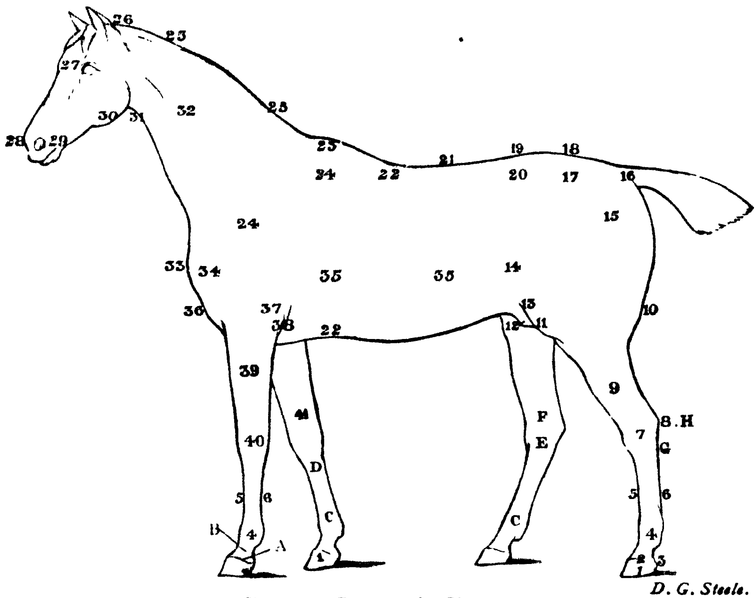


FIG. 39—Points of a Horse

1. Hoof
2. Coronet
3. Heel
4. Fetlock or pastern joint. B. The pastern
5. Cannon bone
6. Back sinew or tendon
7. Hock
8. Point of hock
9. Second thigh or gaskin
10. Haunch or lower buttock
10–20. Thigh
11. Stifle
12. Sheath
13–14. Flank
15. Hip joint
16. Root of tail or dock
17. Rump
18. Croup or "quarter"
19. Loins
20. Point of hip bone
21. Back
22–22. Girth or chest measurement
23. Withers
24–24. Shoulder blade (*scapula*)
25–25. Crest
26. Poll
27. Forehead
28. Muzzle
29. Nostril
30. Jaw
31. Throat or windpipe
32. Neck
33. Point of shoulder
34. Shoulder
35–35. Front ribs and short ribs behind, forming the barrel
36. Chest or breast
37–34. True arm (*humerus*)
38. Elbow
39. Arm (or fore arm)
40. Knee
41. Chestnut, castor or callosity

Seats of Common Diseases.

A. Side-bone
B. Ring-bone
C. Wind-gall
D. Splint
E. Spavin
F. Thorough-pin
G. Curb
H. Capped hock

to the making of a good horse, some are related to the special purpose for which the particular animal is to be used, *e.g.* draft, harness, or saddle. Other things are regarded as desirable in all breeds and types, and these may be now briefly mentioned. The

head should be of good width between the eyes, and the eyes themselves prominent and of good size. These points denote intelligence and docility. The nostrils should be large and open to permit of free breathing. The neck should be of good length. The shoulder should be at least moderately sloped back, as an upright scapula almost invariably makes for a stilted gait. The back and loin should be short, nearly straight, and thickly clad with muscle in order to give strength; too short a back, however, is often associated with a lack of freedom in movement, especially at the trot. The hind quarters should be long and wide, and not too steeply sloping to the tail. Large fore arms and thighs are important as indicating strength. Chest and middle should be deep in order to give, on the one hand, space for heart and lungs, and on the other, capacity for food. For similar reasons the ribs should be well "sprung" or rounded. The knee should be large, the hock broad, and the cannon bones "flat," *i.e.* the tendons should be large and set well back from the bone itself, in order to give the necessary strength and freedom of movement. A fair length and moderate slope of pastern are necessary in order to break the concussion when the foot meets the ground, but too much length or slope involves weakness. The feet should be wide in proportion to their length, the soles concave, and the substance of the hoof tough and durable. The legs should be well knit under the body, and should be moved freely and straight.

The gaits natural to most horses are the *walk*, *trot*, and *gallop*. Some horses develop, also naturally, either the *amble* (or running walk) or the *pace*. The chief additional gaits to which horses may be trained are the *canter*, which is a restrained and modified gallop, and the *rack* or "single-foot." Of these various modes of locomotion the simplest are the trot and pace. The trot is a diagonal two-beat gait—that is, the off fore and near hind move together and meet the ground at the same time, making one beat; the near fore and off hind similarly move together and produce the second beat, the intervals between the beats being the same. Young horses frequently "strike" or "click" when at the trot, the toe of the hind shoe meeting the sole of the fore shoe just as the former is meeting and the latter leaving the ground. In the trot the rider generally "posts"; that is, he rises in his stirrups in unison with one or other pair of legs—generally with the near hind and off fore—and thus escapes the jolt of the second beat.

In the pace (which is rarely found except in American pacer-bred animals) the left pair and the right pair of legs move together, as in a camel's "trot." This sidelong gait is both uncomfortable and unsafe for a rider, but in a harness animal it is not objectionable, and is on the average slightly faster than the trot.

The walk, amble, and rack may be grouped as symmetrical four-beat gaits—that is, each foot is moved in different time from the others and makes a distinct beat, while the movement of the left leg, in each case, is similar in amount and opposite in time to that of its right fellow. The chief difference between the three is in speed. The amble is performed at a rate intermediate between those of the walk and trot. It is a good saddle gait, comfortable for the rider and easy for the horse, and is favoured in many countries where long distances have to be travelled. The rack is performed at a speed faster than that of a sharp trot. It is a showy gait, and a comfortable one for the rider, who has nothing to do but to sit still in the saddle. It makes, however, very heavy work for the horse; animals are trained to it with difficulty, and it is regularly developed only in the American saddle breed.

The canter and gallop are unsymmetrical gaits, *i.e.* the movements of the one leg are not matched by those of its fellow. A horse may canter or gallop either "right leg leading" or "left leg leading," and may be trained to strike off in either way or to "change the leg" at the rider's will. In the gallop the four beats follow each other in very rapid succession, and there succeeds a relatively long interval in which each leg in turn leaves the ground, and the horse is suspended in mid-air with all four gathered under him. The canter is a very comfortable gait for the rider, and in saddle-bred animals it forms an easy one for the horse.

The particular gaits that are required vary with the purpose for which the animal is to be used. Heavy draft animals perform all their work at a walk, but should be able to trot freely and easily on occasion. The principal gait of the harness animal is the trot (or alternatively and exceptionally, the pace), but a free and rapid walk is also to be desired. Ordinary saddle horses should be trained to walk, trot, canter, or gallop at the rider's will, while the American ("gaited") saddle horse is required to show five distinct gaits, viz., the walk, trot, canter, and rack, together with the walking trot, or one or other of two somewhat similar slow movements.

From the utility point of view, horses (including ponies) are classified as saddle, harness, draft, and pack. The first type is required to carry a rider, the second to draw a light vehicle at considerable speed, the third to pull, and the last to carry loads at a moderate or slow speed.

The Saddle Horse.—As far as concerns this country, the hunter and the polo pony may be taken as representative types of saddle horses. The former is typical of the larger, the latter of the small sort of animal for actual utility purposes.

Hunters are classified according to the weight they are judged to be capable of carrying in the field. One system is to make 12 st. the minimum for the light-weight class, and 13 st. 7 lb. the minimum for the heavy. More elaborate classifications are adopted at the larger shows. The qualities specially desired in a Hunter may be summarised as follows:—

1. *Speed.*—He must be fast at the gallop and should show a collected and easy movement at the walk, trot, and canter. Very high action is generally incompatible with great speed, and hence is not wanted.

2. *Staying Power.*—He should be able to gallop at a good speed over three or four miles of ordinary mixed country, taking fences as he goes. Staying power can never be finally judged without actual test, but a large nostril, a good width between the angles of the jaw, and a deep capacious chest are useful indications of it.

3. *Strength.*—The muscles chiefly used in galloping under a rider are those of the back, loin, and hind quarter. The back and loin should be short, wide, and thickly covered with muscle, while the quarter should be long, wide, and strong, the muscles carried well down towards the hocks, and the gaskin or second thigh wide from front to back.

4. *Durability.*—The limbs and joints must be strong enough to withstand the stresses to which they are subjected. The heaviest of these occur during jumping—on rising they are greatest in the hock, and on landing in the tendons and ligaments of the fore legs and the bones of the pasterns. Hence broad clean hocks—neither too straight nor too bent—and large bone and tendons in the fore leg are points of great importance.

5. *Temperament.*—The animal must have plenty of courage and yet be susceptible to such training as will place it completely under the control of its rider. This may be judged to some extent

by the appearance of the head, the expression of the eye, and the carriage of the head and ears. A long neck, fine at its junction with the head, generally makes for easy control by the bit, whereas a short, thick neck generally means difficulty in control. Jumping ability, which is largely a matter of temperament, cannot be judged except by trial.

6. *The Comfort of the Rider*.—The withers should be high and fairly thin, to provide a comfortable seat. The gaits should be smooth and easy and the stride long, the feet being carried rather low, especially at the canter and gallop. Good length and slope of pastern also make for comfort by breaking the impact of the leg on the ground.

In size, hunters range from about 15·1 to nearly 17 hands,[1] most being between 15·3 and 16·2. The weight-carrying capacity is not a function of height but rather of general build, the shorter-legged and stronger-boned animals being generally up to greater weights, if somewhat slower, than the taller and finer-boned types.

The polo pony may best be described as a weight-carrying hunter in miniature, with, if possible, a greater measure of intelligence, in order to permit of greater refinements in training. Great nimbleness and particularly cleverness in turning are necessary in playing ponies.

The American or gaited saddle horse is an interesting type that has been developed in the direction of great style and symmetry, combined with high endurance at moderate speed, and a great measure of comfort for the rider. It is, however, inferior to the hunter in strength, speed, and fencing ability.

Harness Horses are now bred in very small numbers and the interested reader must be referred to other works for information about them.

Draft Horses.—Of chief importance to agriculture is the draft type, more especially the heavy draft; the qualities desirable in the latter may be summarized as follows:—

1. *Strength*.—This is to some extent proportional to weight, but depends also in large measure on the development of particular muscles and on the efficiency of the transmission of the available power through the limbs. The back and loin should be short, wide, and thickly covered with muscle, while the quarters should

[1] The height of horses is measured to the withers, and the unit used is the hand = 4 in.

be long, wide, and well muscled down to the thighs. Arms and gaskins should be broad, with the muscles prominent. As far as concerns the transmission of power, the legs should be closely knit to the body and placed well underneath it; they should be moved freely and straight. Serious defects under this head would be a long and bare back, narrow quarters and thin upper thighs, wide waddling action in front, or a tendency for the hocks to twist outwards when they are submitted to the strain of draft.

2. *Endurance.*—Lung space—a deep, capacious chest—is of importance, but perhaps of rather less consequence in the draft animal than in horses that work at a high speed. Most horses that fail to stand up to severe and long-continued work in draft do so from an insufficient capacity for food. The good feeder, who can be known by his well-rounded ribs and deep capacious belly, will generally be found to have great endurance, whereas the tall, light-ribbed animal with flat sides readily gets weak and out of condition.

3. *Wearing Qualities.*—Apart from unsoundnesses like roaring and stringhalt, the useful life of the draft animal is terminated, in a large majority of cases, by some breakdown in the feet and legs. The common troubles are sprain of the tendons, ring-bone, side-bone, and navicular or other disease of the foot. Hence special attention must be paid to "under-pinning." The cannon bones should be of good size, but must show "quality," *i.e.* they should be clean and hard, with the tendons well set back and large, giving the leg a markedly flat shape. The pasterns should be of good length (they can, however, be too long) and should slope at about 45°. The foot should be wide at the hoof head, neither flat nor steep, and the substance of the hoof should be tough and strong.

4. *Speed.*—The draft animal should have a long stride and a free, straight, active, and easy walk. An animal with a short-stepping, stilted action either cannot walk out at a reasonable speed, or does so with a great wastage of effort. The animal should be able to trot freely and rapidly when required, but there is no particular advantage in high knee or hock action.

5. *Temperament.*—The draft horse should have pluck and energy, without being highly strung or intractable. His head will show less refinement, but more strength than that of the saddle type; it should be carried fairly high and the expression should be alert.

As regards size, it may be said that a height of 17 hands is sufficient for a heavy draft animal, if he be thick of body and proportionately built. Many good horses are under this height, and females are generally considered big enough for breeding if they reach 16·2. A good weight for a mature gelding in working condition is 14 to 15 cwt., or, say, 1600 lb. The largest stallions in show condition occasionally exceed a ton (2240 lb.), though 18 cwt. or 2000 lb. is more usual.

The light draft type may be described as something intermediate between a heavy draft and either a weight-carrying hunter or a harness horse. It will show less weight and strength than the heavy draft, but more activity and speed. Since it will have to perform a good deal of its work at the trot, it should show freedom and ease in this gait, and should be hard-limbed and sound of feet to withstand the heavy wear and tear of fast street work. In general, the light draft type is not a very profitable one to breed, since the market requirements for vanners and light lorry animals are now very small. It makes, however, a useful farm horse for the lighter classes of soils, and on certain farms for miscellaneous light tasks.

The pack type of horse is one of minor and decreasing importance, since its use is confined to districts where the roads are not fit to carry vehicular traffic. The most generally useful sort of animal for the purpose is a large pony or small sturdily built horse, sure-footed, active, and docile.

BRITISH BREEDS

The Thoroughbred or English racehorse (Plate LV, *A*) is of almost pure Eastern blood. It may be said to have originated in an importation of some forty mares—mostly Barbs—made by order of Charles II. During Charles's lifetime these mares were kept as a Royal Stud, and at his death they were sold and dispersed throughout the country. Of many stallions imported both before and after that time, by much the most important were the Byerly Turk, imported in 1689, Darley Arabian (1706), and Godolphin Barb (1724). The blending of these different blood lines, together with long-continued and rigorous selection on the basis of racecourse performance, has produced an animal that is far superior in speed to any modern Oriental breed, and is by much the fastest horse in the world.

Modern Thoroughbreds show a good deal of variation in type, chiefly because there is, and has been, little or no selection except that based on racecourse performance. The height varies from the one extreme of under 14·2 to the other of over 17 hands, the average being probably between 15·2 and 15·3. The head is lean and refined, the eye large and prominent, and the nostril wide. The courage of the breed is proverbial, but the temperament is sometimes objectionably highly strung and occasionally vicious. The neck is long, rather thin and muscular, with a large windpipe, and is carried rather low. The chest is capacious, but deep rather than wide, and the shoulder is preferably but by no means invariably well sloped. The back and loin are very generally short, straight, and muscular; the croup is commonly of good length but varies in conformation, being sometimes level, with the tail set on rather high, sometimes rather steeply drooping. The bones are clean and hard, with the tendons sharply defined and well set back. Small "weedy" bone and long slight pasterns are objectionable. The movement should be smooth and easy, the stride long, and the legs carried rather low. The commonest colours are bay and brown, with chestnut, grey, and black following in order of frequency.

From the utility point of view Thoroughbreds vary greatly in value. Natural toughness, stamina, courage and speed are constant assets, but it is only when these qualities are combined with strength and wearing qualities that they make for commercial value. The long-legged, slightly built, and light-boned animal is often a good flat racer, but otherwise is of very little use. Such "weedy" animals, if they fail to win on the racecourse, are almost worthless. On the other hand, the stoutly built and big-boned animal, even if he is not fit to win races, forms an ideal saddle-horse sire and possesses great commercial value. Many breeds of light-legged horses are indebted to the Thoroughbred for endurance, speed, and courage.

The Arab (Plate LV, *B*) has a history that stretches back to about the beginning of the Christian era, and the purity of the breed has been jealously maintained for the greater part of this long period. Knowledge of pedigrees extends over many generations. Careful selection, with very special attention to such qualities as courage and endurance, has been carried on by the Arabs for a long period, and the modern breed is distinguished by these qualities in a very marked degree. From the Thoroughbred,

to which he is closely related, and which he resembles in a general way, the Arab is distinguished by several fairly constant characters. On the average he is smaller, 14·2 hands being perhaps the average height. The head is wider between the eyes and tapers more towards the nose; the neck is more arched, the head is carried higher and the shoulder is more oblique; the croup is generally longer and typically more level, with the tail higher set on; the withers are commonly rather thicker.

In speed the Arab is far inferior to the Thoroughbred. He is, however, capable of carrying a heavy weight in proportion to his size and is unexcelled in endurance; many animals have been ridden 50 or 60 miles a day for several days on end. In long-distance tests the breed is generally supreme. An Arab Horse Society has been established in England, and published the first volume of its Stud Book in 1919.

The Hunter and the Polo Pony (Plate LVI) cannot yet be regarded as breeds in the strict sense, but are rather commercial types. Registration with a view to the establishment of actual breeds has, however, commenced, foundation stock being entered by inspection. Hunters generally carry a large proportion of Thoroughbred blood, the other elements in their breeding being very varied. "Clean bred" hunters are by no means unknown, but it is exceptional to find Thoroughbreds with the necessary bone and substance to carry heavy weights. The type required in flat country such as the Midlands is different from that suited to hilly areas; the latter must be short-legged and sure-footed rather than specially fast. The polo-pony breed, when formed, will contain the blood of several native breeds of ponies such as the Welsh, Exmoor, and Dartmoor, blended with that of the Thoroughbred and Arab.

Ponies.—Of the native British ponies, the smallest and certainly one of the oldest breeds is the **Shetland**. Standing generally under 40 in. in height (the maximum height for mature animals is 42 in.), the Shetlander is very stoutly built—rather like a heavy draft animal in miniature—and very strong for its size. In their native isles the ponies are used as pack animals, especially for the carrying of peat. Being generally docile and easily trained, they are very popular as riding ponies for young children.

The Western Isles Pony, or light-type Highland pony, is native to the Hebrides, some of the best and most typical being found on Barra. It is generally between 12 and 13 hands high

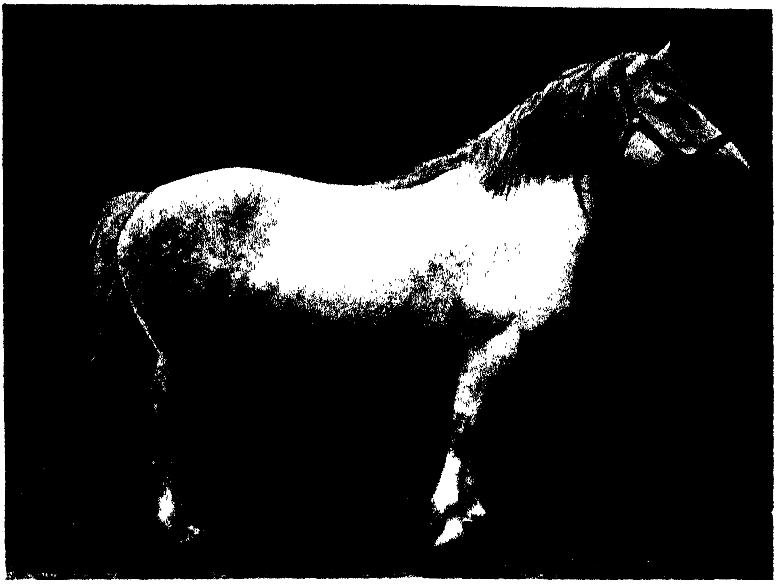
and is of good saddle conformation, though often steep of shoulder and rather sickle-hocked. The quality of bone is excellent and the breed is very active and, of course, exceedingly hardy. It is used, like the Shetland, principally as a pack animal.

The heavy or Mainland type of **Highland Pony**, frequently spoken of as the Garron (Plate LVII, *A*), is found in the Central Highlands of Scotland, notably in Perthshire. Averaging nearly 14½ hands in height (the maximum allowed by the breed standard) the breed is very stoutly built, distinctly "drafty" in type, with rather heavy shoulders and thick withers. The neck is highly crested, the mane abundant. The "bone" is sometimes too round and the legs carry, in winter, a good deal of long feather. Distinguished for his great hardiness and longevity, the Highland pony is used by the smaller glen farmer as an all-purpose horse—for riding, driving, hauling, and carrying; during the stalking and shooting seasons many find employment in carrying deer or game. Grey is perhaps the commonest colour.

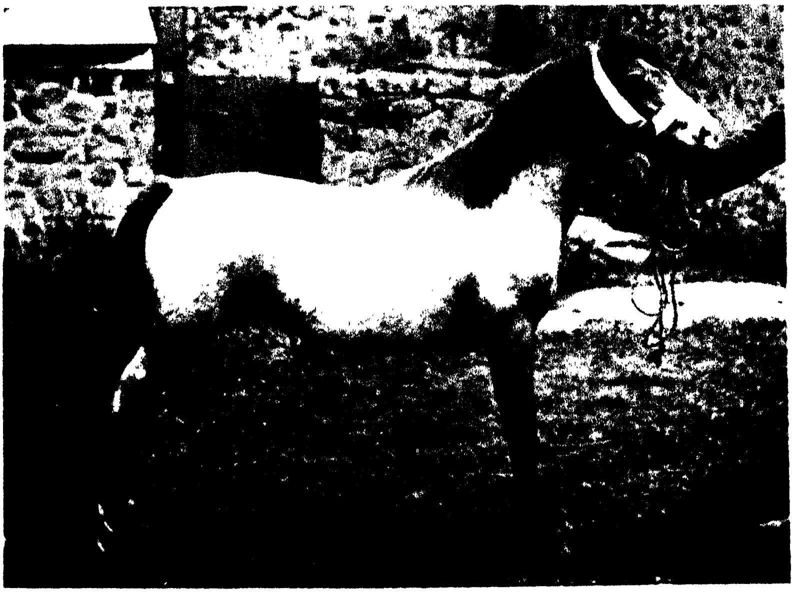
Of rather similar type to the last is the **Fell Pony** of Cumberland, Westmorland, and West Yorks. It is generally some 2 or 3 in. smaller than the Highland, but is built on the same general plan—thick and short of leg, with large bone. It is believed to be descended from the old Galloway pony, which was famed for its toughness and strength. The **Dales Pony** of East Yorks and Durham is similar to the Highland pony but generally bay or brown in colour. It is larger than the Fell pony and might almost be regarded as a small draft horse, since many specimens exceed 14·2 or even 15 hands in height. The general conformation is rather massive, but the breed is both sure-footed and fast. In past times many were employed for pack work, and some are still taken for colliery purposes: their chief use, however, is for farm work on the smaller holdings of the Dales.

The Exmoor and Dartmoor are ponies of saddle type. The latter stand about 12·2 hands, the former perhaps 2 or 3 in. less. They have well-bred heads, good shoulders, and hard bones, but, rather frequently, drooping quarters and sickle hocks. Crossed with small Thoroughbred or Arab sires, they produce excellent riding ponies.

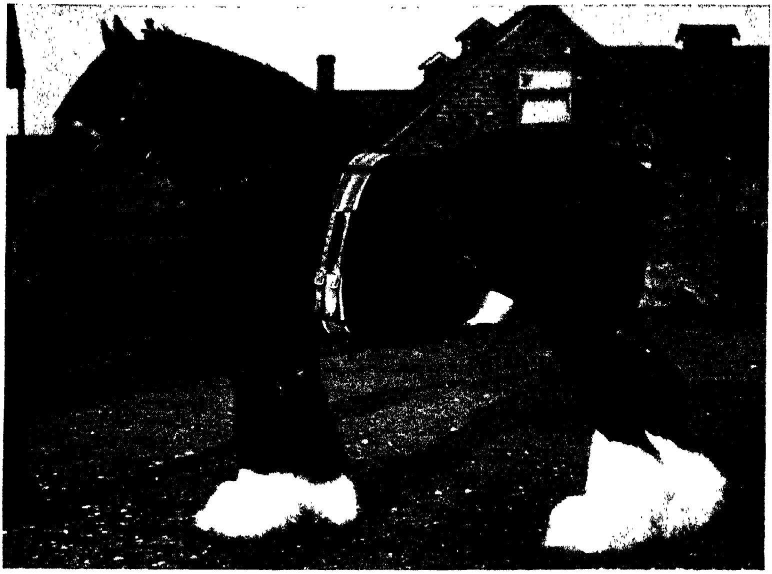
The New Forest type shows rather less breeding than the foregoing, and generally a heavier and more upright shoulder; the legs, however, are better built. Forest-bred specimens run from 12·2 to 12·3 hands.



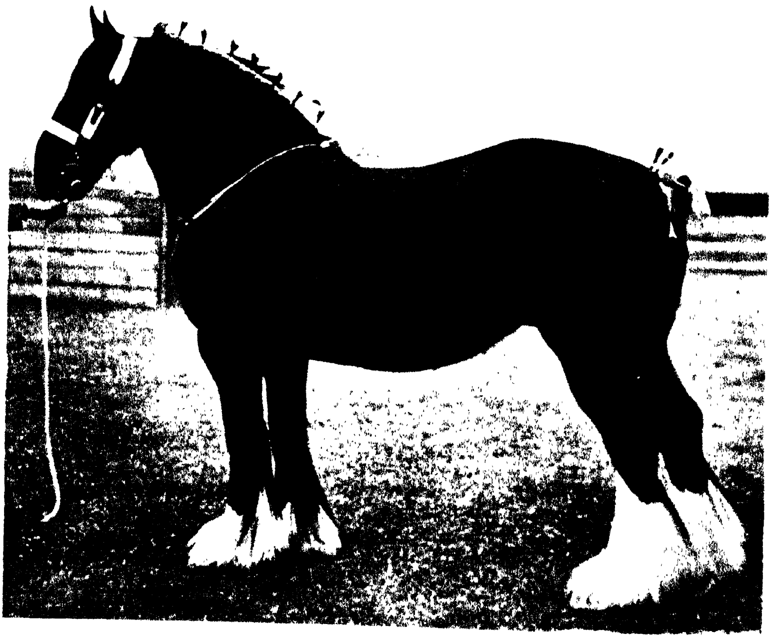
A. Highland Pony Mare



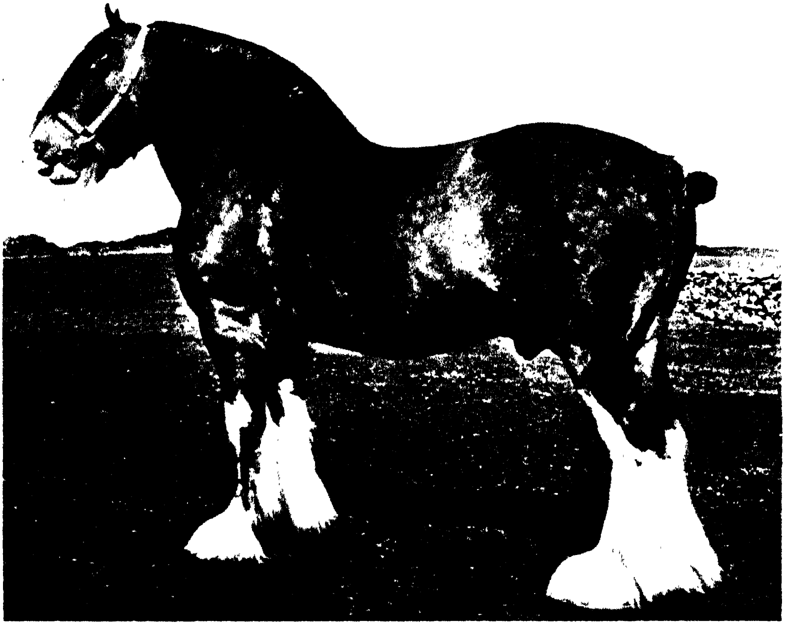
B. Welsh Pony



A. Shire Stallion *Farmer and Stockbreeder*

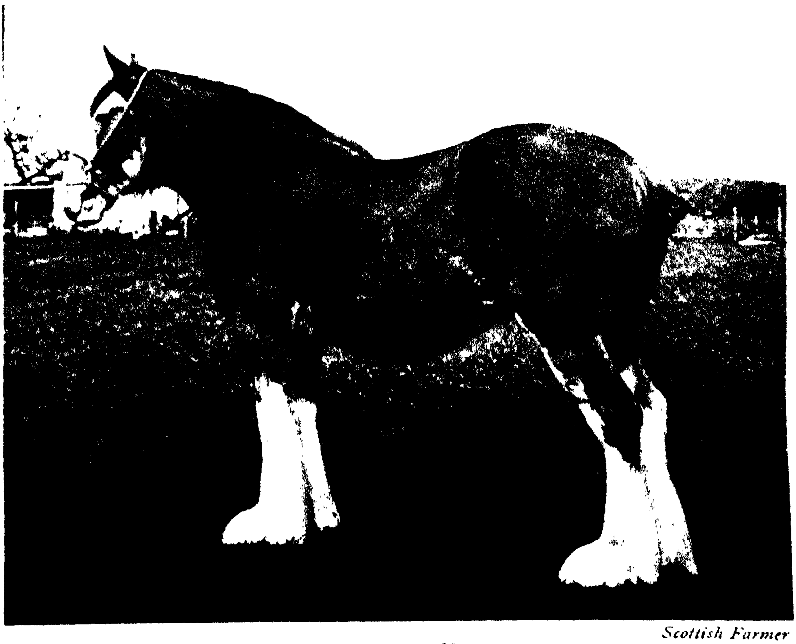


B. Shire Mare *Farmer and Stockbreeder*



Scottish Farmer

A. Clydesdale Stallion



Scottish Farmer

B. Clydesdale Mare

A. Suffolk Stallion

B. Percheron Stallion

The Welsh Pony (Plate LVII, *B*), which has existed from very early times on the moors and mountains of Wales, is a breed of very considerable importance, forming perhaps the most valuable foundation stock for the production of saddle ponies. Two types are recognized and are registered separately in the Stud Book. The smaller and lighter type (under 12 hands) is of saddle conformation, while the larger (up to 12½ hands) has higher action and is more of the harness type. In general these ponies are very hardy and enduring, and show great freedom and speed in movement.

The Welsh Cob is derived partly from the foregoing, with an infusion, in early times, of some Thoroughbred, Arab, and Hackney blood. Typical specimens measure from 13·2 to 14·2, have durable limbs, and show high-stepping action and considerable staying power. They are used as riding animals by farmers in the remoter parts of Wales.

The Heavy Draft Breeds now recognized in Britain are the native Shire, Clydesdale, and Suffolk, and the recently introduced Percheron and Belgian. The Clydesdale is the breed of Scotland and the four northern counties of England, and is the chief of the draft breeds in Ireland. The Suffolk is native to East Anglia and has only recently spread beyond the borders of this province. The Shire is found throughout the rest of England and Wales, excepting only mountain and moorland districts.

The Shire (Plate LVIII) is regarded as the direct descendant of the Old English war horse, or Great Horse. This latter was derived partly from the horses that existed in Britain before the Roman invasion, partly from heavy horses that were introduced at various times, chiefly from Flanders. In olden times the Great Horse was valued for his ability to carry the immense weight of armour, etc., of the mounted knight, and various kings of England—from John to Henry VIII—were at considerable pains to maintain or increase the size and quality of the breed. The use of horses as the chief draft animals on the farm is a comparatively recent thing, for till the eighteenth century over most of this country the bulk of field work was done by oxen.

Careful and systematic breeding of Shires has been carried on since the middle of the eighteenth century, and some modern pedigrees go back a hundred years or more. In the days before the formation of a breed society (1878) there was a good deal of variation in type from one district to another, but the breed has

been levelled up by continuous interbreeding of the local variations. Of the early Shires it may be said that many were weighty and powerful animals; but upright pasterns and steep, narrow hoofs, a want of quality in bone, and unsoundnesses like side-bone, were common faults. The aim of the Shire breeders has been to eliminate these defects, while preserving or even increasing the size and weight. The strict veterinary inspection of all animals competing at the shows of the Shire Horse Society has had a very beneficial effect. Twenty years ago there was a tendency to aim at an excessive quantity of "feather," but the present-day preference is for legs almost as "clean" as a Clydesdale's.

The modern Shire is probably the weightiest of all horses, though the Belgian is sometimes regarded as first in this respect. Mature stallions of the best class, measuring generally 17 hands or over, often reach a weight of 20 cwt. when in show condition. The head is heavier and coarser than in other British breeds and the eye is smaller. Typically the back is short, wide, and very strong; the ribs both deep and widely sprung, giving a middle of great capacity; the quarters very wide and powerful, but often somewhat short and drooping. The fore arms and thighs are of great size, and the bone should measure at least 11 in. below the knee and 12 in. below the hock—the larger the better, so long as it is clean and flat. The pasterns are of moderate length and preferably well sloped. The feet are now generally of good size—wide at the heels and open at the hoof head. The "feather" is long and straight, and rather strong in quality. Curly or woolly feather is regarded as objectionable. Common colours are bay, brown, and black, with grey, chestnut, and roan less prevalent. The mare, apart from her smaller size and the feminine character in her head, is relatively longer in body and shorter legged than the stallion. The temperament of the Shire is commonly very docile—sometimes phlegmatic. In general the animal gives the impression of great strength and massiveness. He is an excellent feeder and has great endurance on slow work.

The Shire, while fairly popular in many foreign countries, has not on the whole competed very successfully with other draft breeds.

A cross between the Shire and Clydesdale combines a good many of the best qualities. The progeny of a mare of this cross by a registered Shire stallion is eligible for registration in the Shire Stud Book.

The Clydesdale (Plate LIX) may be said to have had its

origin during the first half of the eighteenth century in the interbreeding of the native horses of the Upper Ward of Lanarkshire with colts introduced from England; some at least of the latter were of Flemish breeding. The most famous of the pioneer breeders was John Paterson of Lochlyoch who, about 1715, introduced from England a black Flemish stallion which has been regarded as the foundation sire of the breed. The earliest horse to which pedigrees can now be traced is "Glancer," foaled about 1810, and probably descended, in the female line, from the Lochlyoch stud. Occasional crossing with Shires was done up till about 1890, and a good many three-quarter blood Clydesdales, with the Shire cross, are entered in the earlier volumes of the Stud Book. Many breeders believe that the separation of the breed from the Shire was a mistake, as the original differences were not very marked. At times the breeds have drifted very far apart, but the less massive and cleaner-legged type of Shire that is now preferred is not very different from the heavier-boned sorts of Clydesdale.

The Clydesdale is similar in height to the Shire, the stallion being 17 hands or over and the mare about 16·2. The general build, however, is less massive, the legs being proportionately longer, and the body neither so deep nor so wide. The head shows more quality and refinement, the eye being larger and the muzzle finer. The neck is rather longer and more crested, the head more gaily carried, and the shoulder has on the average more slope. The back is more frequently faulty than in the Shire, being sometimes too long, sometimes hollow, and sometimes rather bare of muscle. Flatness of rib and shallowness of heart or belly are commoner faults. The quarters are usually longer and more level, but narrower when viewed from behind. The arms and gaskins are not so large and are shorter in proportion to the length of the cannon. The bone of the Clydesdale is much smaller but is harder, flatter, and cleaner, and the feather, which is more silky in quality, is confined to the back of the leg. The pasterns are longer and have more slope; the feet are relatively larger and wider but with a more frequent tendency to flatness. The Clydesdale, as a breed, is very free from leg troubles like grease, side-bone, ring-bone, navicular disease, etc., and the average working life, particularly when tested against other breeds on paved streets, is exceptionally long. The breed is also remarkable for its straight, free, and close movement, and shows great ability and cleverness in handling loads. In general it may be said that

the Shire excels in weight and strength, and in endurance; while in speed, agility, and wearing qualities the Clydesdale is pre-eminent. The temperament of the Clydesdale is more mettlesome and nervous than that of the Shire; he is more troublesome to break and requires more horsemanship on the part of his driver. Another point of difference is that the Shire matures at a much earlier age than the Clydesdale, so that the difference in weight is far more marked at the yearling or two-year-old stages than in aged animals. Clydesdales are of all the ordinary colours, bay and brown predominating, while chestnut and grey are rare. White faces and legs are almost constant features, and splashes of white on the belly, or white hairs irregularly mixed throughout the coat, are becoming increasingly common.

The Clydesdale is a common draft breed in Canada, New Zealand, Australia, the United States, and many other countries. Broadly speaking, however, it is less popular than the Percheron. The chief defects of the breed, as urged, *e.g.* in the United States, are its tendency to flatness and shallowness of rib, and narrowness of build, with a consequent inability to keep in condition when exposed to heat or cold or subjected to severe work or scarcity of food.

The Suffolk (Plate LX, *A*) is the least numerously represented of the three native draft breeds. It has been recognized as a distinct local type for several centuries, but some infusion of trotting blood was made over a hundred years ago. The average height is 1 or 2 in. less than that of the Clydesdale or Shire, but the weight is not notably less than that of the Clydesdale. The general build is thick, wide, and low set. The ears are rather short, the neck crested, the chest deep and wide, the barrel large, the ribs well-rounded, and the quarters wide and heavily muscled, though often rather steeply sloping. The bone is rather light, but not more so than in many modern Clydesdales. The legs carry practically no feather. The pasterns are rather short and upright, especially the hind ones. The feet formerly showed a tendency to flatness but the breed has been greatly improved in this respect. The Suffolk is active, but the movement is not so straight and true as in the Clydesdale. The colour is some shade of chestnut, with sometimes a white spot or blaze on the face. White feet are regarded as objectionable. The outstanding merit of the Suffolk is his constitution. When well fed he puts on a great reserve of fat, and he is easily kept. On ordinary work he

can go long hours without food, and stands exposure and scarcity very well. In draft he is remarkably steady and he lives and works to a long age. The mares are exceptionally regular breeders. The Suffolk was long in obtaining recognition outside his native district, but during recent years several studs have been established in other parts of England.

The Percheron (Plate LX, *B*) derives its name from the old French district of La Perche, lying within a radius of some forty miles from the town of Nogent-le-Rotrou, situated about a hundred miles south-west of Paris. The breed contains a good deal of the same blood as the other draft breeds, but was influenced to a considerable extent by the introduction of Eastern (Arab) blood. In coaching times the Percheron was used chiefly for road work, and its evolution into a heavy draft breed has occurred since the widespread development of railways. Its main characteristics may be summarized as follows:—

The height averages 16·2 for stallions and 16 hands for mares. The weight is rather great in proportion to the height, but even by this measure the Percheron is perhaps the smallest of the heavy draft breeds. The head is rather lean and shows a good deal of breeding. The neck is highly crested and the shoulder long and oblique, the chest deep and wide. Width and strength of back and roundness of rib are very striking characteristics, but the depth of back ribs is not so uniformly good. The quarters are wide, but often short and generally rather steeply drooping, the tail being set on low. The bone is fairly hard and fine though somewhat round, and the legs are free from long hair. The pasterns are somewhat short and upright, and the feet of reasonable size, shapely, and very sound and durable. The hind leg has often too much "set"—*i.e.* is too crooked—to please the eye of British judges, and the hock is often lacking in breadth and is too round and fleshy. The movement is sharp, with rather high knee action at the trot, but the front action is not so straight as could be desired. The temperament is very good—docile, yet active and willing. The common colours are grey and black, with bay and brown rare. The Percheron is the favourite draft breed in the United States, where it owes its popularity to its clean legs, its quiet temperament, good constitution, and its high power of endurance on rather fast work. Importations of pure-bred Percherons into Britain were of no importance until 1918, when the British Percheron Horse Society was formed.

Belgian horses were imported into Britain in considerable numbers during the few years up till 1939. The breed is a very old one, related to the Flemish animals which played a part in the formation of the Shire and Clydesdale breeds. The Stud Book dates from 1886. The general build of the Belgian is heavy and compact, with a very large girth in proportion to the height. The neck is short, the back straight and strong, the rump rather short and drooping. The short legs are practically devoid of feather. The bone is rather round and the feet tend to be small. The temperament is very docile and the horses are willing workers. The commonest colour is chestnut, though bay, brown, and roan also occur.

BREEDS AND NUMBERS OF LICENSED STALLIONS

The relative numerical importance of our heavy draft breeds, and a number of other breeds of horses and ponies, is shown in the table opposite, which gives the numbers of stallions—pedigree and non-pedigree—for which new licences were issued in 1939 and 1946 respectively. The great decrease in total numbers reflects the progress of farm mechanization. The figures were supplied by courtesy of the Government Departments.

HORSE BREEDING

Breeding animals should be chosen primarily for individual merit, and should preferably be of pure breed and of good pedigree. Continued and indiscriminate crossing should always be avoided as it gives a greatly increased chance of "misfits." In the breeding mare, quality, trueness to type, and roominess of body are more important than size (height). Freedom from any hereditary tendency to unsoundness is most important. The list of diseases that are held as disqualifying stallions from registration under the Horse Breeding Act includes cataract, roaring or whistling, bone spavin, ring-bone, side-bone, navicular disease, shivering, stringhalt, and defective genital organs.

Fillies may be mated for the first time either at two or at three years old. The question whether it is advisable to breed at the earlier age must be answered according to circumstances—according to the animal's size and condition, and whether it is desired that she should make the fullest growth of which she is

Breed and Type	England and Wales		Scotland	
	1939	1954	1939	1953
Heavy—				
Shire	1092	29	1	...
Clydesdale . .	215	5	459	20
Suffolk . . .	255	12	2	...
Percheron . .	92	14	6	...
Cleveland bay . .	...	2	...	...
Others . . .	45	...	...	...
Total heavy horses .	1699	62	468	20
Light—				
Arab	15	14	1	1
Thoroughbred . .	166	29	4	2
Hackney . . .	...	24	...	12
Hunter . . .	...	...	2	...
Others . . .	28	...	...	...
Total light horses .	209	67	7	15
Ponies and Cobs—				
Dales	13	1	1	...
Fell	7	1	...	1
Highland . .	1	2	25	8
Polo and riding .	13	5	1	...
Shetland . . .	5	2	10	9
Welsh pony . .	7	19	...	2
Welsh cob . .	41	1	...	...
Others . . .	...	3	...	...
Total ponies and cobs	87	34	37	20
Others . . .	...	...	34	1
Grand total . .	1995	163	546	56

Numbers in Northern Ireland (1953) were 24 Clydesdales, 11 Thoroughbreds, and 34 of other breeds including ponies.

capable. Colts at two years old may serve a limited number of mares—generally not more than a dozen. Three-year-olds should be restricted to about sixty and aged horses to about eighty. Much, however, depends on the individual characteristics of the stallion, on his constitution, and the effectiveness of his services.

The period of gestation averages rather more than eleven calendar months and varies quite commonly as much as a fortnight either way. It is longest in mares that foal in winter or early spring and shortest in those that foal in summer. The first heat begins four to seven days after foaling and ends on the tenth to the thirteenth day after foaling. The average duration of the period of heat is seven days, but there is much variation. It is longest in early spring—and especially in a cold spring—and gets shorter in summer and autumn. The average time between successive heats is twenty-one days, but the best way to calculate the time of onset is to count sixteen days from the end of the previous heat. The foaling season may be at any time between January and September. With Thoroughbreds, where age is counted from the beginning of the year, and where two- and three-year-olds are very often trained and raced, it will obviously be advantageous to have the foals early, and most are dropped between January and March. For ordinary farm horses in this country the most generally convenient season is April to June, since this entails a minimum of housing and attention for the young animal. In countries where summer work is heavy and winter work very light, it is sometimes arranged to have a proportion of the foals dropped in autumn.

In general the fecundity of the mare is far below that of other domesticated animals. An occasional animal conceives regularly, year after year, at her first service; but it is far commoner for mares to "come back" to the stallion several times, and the proportion that remain barren after repeated services throughout the breeding season may frequently reach 40 or 50 per cent. A service two to four days before the end of the œstrous period is much more likely to be effective than one in the first day or two or on the last day of the heat. Indeed if a mare is still on heat three days after service it is advisable to serve her again. The proportion of conceptions depends partly on the male. Some stallions will "settle" 80 per cent. of their mares, while others, under identical circumstances, will beget very few foals, and a small proportion of apparently normal animals are almost or quite sterile. To ensure good results the stallion must be carefully fed on a good mixed ration, should not be too fat at the commencement of the breeding season, and should have regular exercise during the idle part of the year. As regards the mares, those at grass are more likely to conceive than those kept in stables and on

dry feeding. Mares that are on hard work and lean, and on the other hand such as are over-fat, are much less likely to conceive than such as are in natural thriving condition. Twins are rare and are not wanted, since they are generally undersized even when mature.

Ordinary farm mares are generally required to work regularly during the greater part of the year. It is only when the prospective value of the foal is very high in proportion to the cost of maintenance of the mare that breeding, in itself, is likely to produce a profit. Provided that the mare is in the charge of a skilled and reasonably careful horseman, she may do all classes of farm work during the first six or seven months of pregnancy. In the latter part she should not be put between shafts and should be excused from any exceptionally heavy jobs, but may continue to work in chains right up to the time of foaling. It is a serious mistake to rest the mare for the last few weeks if this entails shutting her up in a box and leaving her without exercise; but if it is possible to turn her out to grass she may go idle without taking harm. The approach of parturition is indicated by a gradual slipping or relaxation of the muscles about the tail head and a swelling of the udder; generally some two days before foaling a waxy secretion will appear on the ends of the teats. As the time approaches, the mare should be placed at nights in a roomy box, and after the appearance of the wax should be kept under close observation. The period of labour is generally short—often less than an hour—and false presentations are comparatively rare. Retention of the cleansing is more dangerous than with other animals.

Some patience is frequently necessary in getting the foal to suck, but interference should be as long delayed as possible. After foaling, the mare should have laxative and nutritious foods—bran mashes, oatmeal drinks, and clover hay. After two or three days, if the weather be genial, mare and foal may begin to go to grass for a short period, which period is extended day by day until after two or three weeks they may be left to lie out at nights. In the case of foals born early in the year, exercise should be regularly given until the weather conditions permit of the animals being turned out. When the foaling falls in summer excellent results are often obtained by turning the mare into a clean and sheltered paddock and allowing her to remain out altogether. Where foaling boxes are used they must be thoroughly disinfected for each new case and must be kept clean.

After foaling, the mare should be left idle for at least a month, and may be so left with advantage until the time of weaning. When work is pressing she may be given light jobs, but should not be overheated nor kept apart from the foal for more than two or three hours at a stretch. If, occasionally, the mother should be put to severe work or overheated, some of the milk should be drawn by hand before the foal is allowed to suck. The age for weaning may be about four months—or up to six months if the mare is not required for work. The separation should be complete and final; the foal must be closely and securely confined out of hearing of the mare, and the latter should be put into regular work in order to dry off her milk. After three or four days' confinement, during which time it is usually fed on bran, oats, and hay, the foal may go back to pasture—preferably with a companion.

If weaning has occurred fairly early in the year, and if good pasture is available, no additional food will at first be necessary in order to keep the weaned foal in thriving condition. Backward animals, or such as have been weaned at an early age, will benefit greatly from a daily mash of bran and crushed oats soaked with separated milk. As the season advances and pastures get bare and less nutritious, the foal should get one feed per day, and later, during the winter, two. A suitable ration for midwinter might be: crushed oats, 4 lb.; bran, 2 lb.; and chaffed hay, 4 lb.—fed either dry or slightly damp and divided into two meals. During periods of frost and snow a little long hay may be thrown out in the field, and many breeders give two or three swedes a day. The foal should be out whatever the weather conditions for some part of each day, but should—except in mild districts or in sheltered situations—be housed at night in a freely ventilated box. With the return of grass in spring, hand feeding may be discontinued, and in April or May the animal may begin to lie out.

Castration is generally performed at a year old or as soon thereafter as the weather is sufficiently mild. Very warm weather should be avoided. The operation involves more danger than with the other species of farm animals but is no less necessary, although some individual stallions, notably Percherons, work fairly well. No one but a skilled veterinary surgeon should be trusted to carry out the operation. Apart from this the only special attention necessary is to the feet. These should be kept well rasped down so that the frog rests on the ground, otherwise the

feet will become long and narrow and an undue strain will be put on the pasterns. On ordinarily soft land the feet will require to be dressed at intervals of four or six weeks.

Summer pasture for young horses should not be of the rich fattening type, since on such the animal is liable to get too heavy for its legs and thus lose activity and freedom of movement. Young horses grow and thrive best when they are given a wide range of moderate pasture and when they are running with other stock, preferably cattle. When kept by themselves on a small area they graze very irregularly and are also much more liable to suffer from intestinal worms. Only Thoroughbreds are normally given grain (oats) while on summer pastures, and then only to hasten growth for early racing.

During the second winter, if fair rough pasture be available, hand-feeding may be confined to a shorter period—say January to March—and the ration may be lighter and less concentrated. Six pounds of grain with a similar amount of hay may ordinarily suffice, but the quantity must depend on the animal's condition and the climate. In no case should the animal be made fat, and it will usually be all the better if it reaches the spring in distinctly lean condition. During the third summer ordinary pasture will again suffice.

The usual age for **breaking** the farm horse is two and a half years. Some Shires are put to work at two, and Clydesdales, in breeding districts or where the winter work is light, are often left till nearly three. In any case the whole process should not be left until the animal is of age to start work. As a young foal it should be made to understand the use of the halter and that there is no means of escape from it. This first lesson may involve a severe struggle. Thereafter it should be gradually accustomed to being handled—to having its legs lifted, etc. When these processes have not been gone through at an early age the preliminary " gentling " of the grown animal is much more difficult.

The first stage of the breaking proper is to put on harness and lead the animal about, in order that it may lose the sense of irritation and alarm at the contact of the tackle. Thereafter it should be driven on long reins for an hour or so at a time, until it answers to the bit; two or three lessons will generally suffice. Care must be taken to avoid damage to the mouth, as repeated bleeding, even if slight, causes the " bars " (on which the bit

rests) to become insensitive. These lessons may be combined with or followed by training in draft, which is best started by means of men pulling against the animal on long rope traces, the pressure on the shoulders being applied gradually while the animal is in motion. Finally, it may be harnessed along with a steady but active horse in the plough, with at first an additional leading rein and a man alongside. Work in shafts should be postponed for a few months. Judgment must be exercised in the matter of the time to be allowed for each stage. Some animals can be put almost straight into work while others may require a week or two of preliminary training. Fractious animals should be trotted round on the end of a rope—preferably on heavy going such as fresh-ploughed land—before each lesson. This preliminary exercise should proceed until the animal is tired enough to be amenable to discipline, but not, except in extreme cases, to the point of exhaustion.

There is a good deal of variation in the methods by which the necessary horses are maintained on the farm. In the remoter country districts many farmers work their animals only until they are five or six years old, at which age they are sold for dray work in cities or to other farms where there is a large amount of road and cart work to be done. Provided that skilled horsemen are available for breaking and training, this scheme has the obvious advantage that the average value of the horses may be expected to appreciate during their period of farm work. Most horses continue to grow in size and strength until they are about seven years old, and if the whole working life is utilized a good animal, barring accidents, may be expected to remain fit for regular work until the age of from fourteen to eighteen years, after which it may fill the post of "odd horse" for two or three years more. When all things are allowed for, the average working life will not greatly exceed ten years, say from three to thirteen years old. The average life is influenced largely by the skill shown in feeding and general management, but also by the amount of road work that falls to be done and, naturally, by the breed and individual character of the horses used.

FEEDING OF WORK HORSES

In Britain, oats and hay form the usual basis of the ration for work horses; and provided the oats be sound and not too new,

and the hay be clean and hard, there are no other feeding stuffs that are so wholesome or so generally useful. Of the various hays, timothy, rye-grass, and good meadow hay are all very satisfactory. Clover is less good, since it is too laxative for animals on severe work. Dusty hay is objectionable in that it spoils the "wind," and mouldy or ill-got material should be avoided if possible. For the winter months, when work is often irregular and the day is short, oat straw is often substituted for hay, and in such circumstances forms a useful fodder, though it is too low in nutritive value for animals on hard continuous work. In northern clay-land districts bean straw is used as a partial or even complete substitute for hay throughout the year. The taste for it is somewhat slowly acquired, but ultimately many horses come to prefer it to other fodders. It is less nutritious than hay, and the concentrated ration must be correspondingly heavier.

Of concentrates other than oats, maize is quite largely used, chiefly because it is often proportionately cheap: 3 lb. give the same energy value as 4 lb. of oats. If it is to form a large part of the ration it must be introduced gradually, and it gives the best results when mixed with oats and dry bran in order to lighten it. Barley makes a good horse corn but wheat is unsatisfactory, being liable to produce colics unless fed with care. Rye is worse. Beans are good up to a moderate proportion—say one-eighth of the grain ration. Crushed linseed, or linseed-cake, is an excellent conditioning food for animals that are run down, but it is too laxative to be fed in quantity to animals on severe work; 1 or 2 lb. of the former or 2 to 4 lb. of the latter are common amounts to feed daily. Molasses or one or other of the various molassed foods is sometimes added as an appetizer to the grain ration, and is useful for shy feeders. A bran mash in place of the usual evening feed of grain is commonly given on Saturday nights as a matter of routine, in order to prevent, by its mild laxative action, the possible ill effects of the following day's idleness. It is specially important when work during the preceding week has been continuous and hard.

On farms where summer work is not very heavy the work horses usually run at grass, and are given a feed of 5 or 6 lb. of concentrate for each half-day that they work. They must be stabled and "hardened up" before the regular autumn work commences.

The amount of the daily ration must be determined according

to the size of the animal and the amount and severity of the work being done. A full-sized, active, heavy, draft animal, on hard and continuous work, will require quite 20 lb. of oats—or its equivalent in other grain—per day, along with nearly the same weight of good hay. The following are examples of rations for a farm horse of average size—say 1400 to 1500 lb. live weight :—

Light or Intermittent Work.	Medium Work.	Continuous Heavy Work.
12 lb. oats.	16 lb. oats.	10 lb. maize.
8 ,, hay.	16 ,, hay.	5 ,, oats.
10 ,, oat straw.	10 ,, swedes.	5 ,, bran.
20 ,, swedes.		14 ,, hay.

The actual expenditure of energy depends to a greater extent on the speed at which the work is performed than on the hours worked or the pull. Hence in the north, where it is the custom to drive horses rather hard, rations tend to be heavier than in the south. In the Midlands and South of England, 12 lb. oats, mixed with 4 lb. of straw chaff and about 14 to 16 lb. of hay, may be taken as an average ration.

In periods of complete idleness the grain ration must be severely restricted, as many ailments arise from overfeeding at such times. In general, of course, the rations must be adjusted to meet the individual requirements of the animals, the object being to keep them in good, hard condition but not to make them fat.

As regards the preparation of the food, the grain should be bruised if possible, a proportion of the fodder should be chaffed, and grain and chaff fed together. This has the double object of preventing the animal from bolting the grain and of saving part of the work of mastication. Some horsemen give the whole of the food in the form of a mixed chop, but the consensus of opinion is that some long fodder is advantageous. The old practice of boiling or steaming roots, grain, and chaff, and feeding the mixture in the form of a warm slop, had nothing to recommend it, and has been very generally abandoned. Feeding should be done not less than three times a day, and at least a full hour should be allowed both for the morning and for the mid-day meal. Water should be given freely four times a day—always before feeding, or, at least, not immediately after a meal. Exception should be made only in the case of an animal in very overheated and overtired condition; in such cases the horse's thirst should be quenched gradually with

half a bucketful of lukewarm water at short intervals until he is satisfied.

Horses at work should be thoroughly groomed once a day. Legs should not be washed often, but should be allowed to dry and be then brushed out. In periods of idleness during winter an hour's exercise should be given at least every second day. Exercise is the more necessary if the animals are suddenly thrown idle after a spell of hard work.

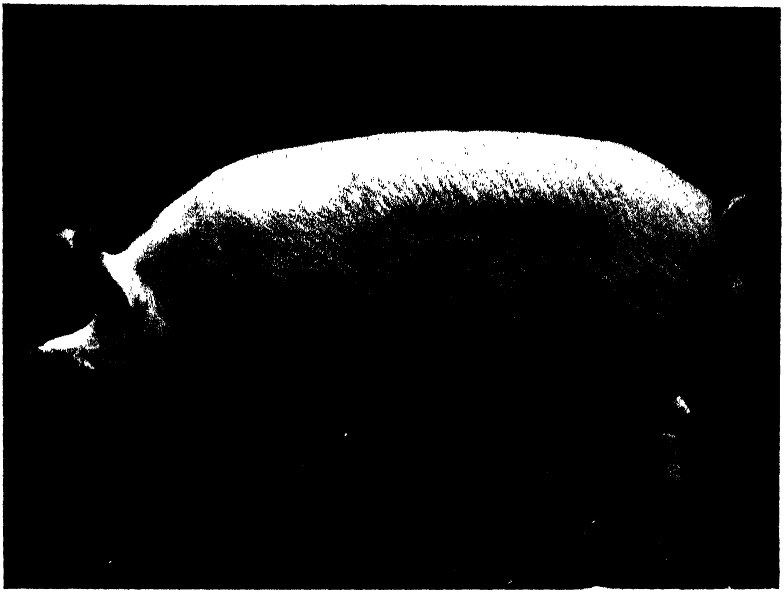
Shoeing should be done at intervals of six or seven weeks, or oftener in cases where the feet are thin or liable to break. New shoes are, of course, not necessary on all occasions. At the onset of winter, but before the coat is fully grown, farm horses should be clipped "trace high"—*i.e.* the coat is removed only from the chest, belly, and thighs, while the head, neck, back, quarters, and legs are left untouched. This plan allows the horse to keep reasonably cool at work and yet leaves the natural protection against rain on the one hand and mud on the other. The end of November is generally a suitable time to clip, and the operation is usually repeated in January. The stable should have ample head room, and should be well ventilated and well lit. Stalls should be 6 ft. to 6 ft. 6 in. wide, and the length from manger to back wall should be about 18 ft. Overhead racks are undesirable because of the risk of hay seeds, etc., getting into the eyes.

Careful routine management must be accompanied by a close watch over individual animals, and early attention must be paid to common ailments such as sore shoulders, "weeds" (lymphangitis), colics, colds, and lamenesses. Horses that are in lean and unthrifty condition should have their teeth examined and filed if necessary. Intestinal worms are another frequent cause of a failure to thrive. A supply of rock-salt in the manger will generally help in the maintenance of health.

ASSES AND MULES

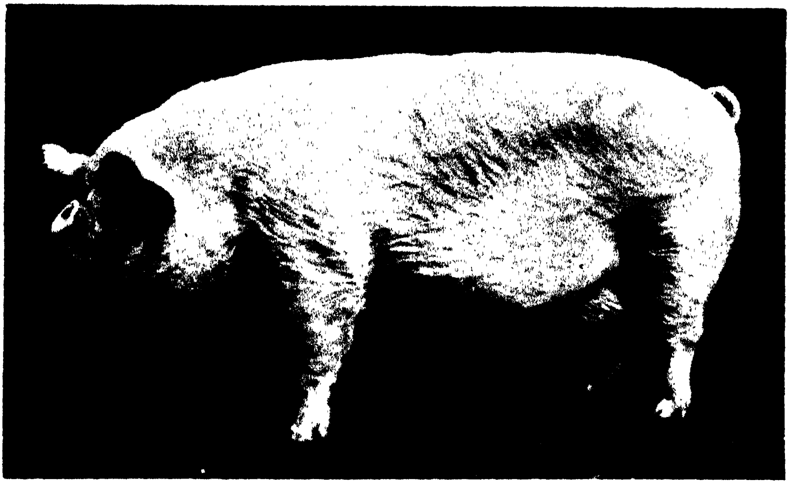
Donkeys are used in this country for farm work, but are generally to be found only on the smallest class of holding, for which they are rendered suitable by their small food requirements. Abroad, they are used as riding and pack animals. The larger breeds, which produce jacks suitable for mule-breeding, are the most valuable. The breeds that are held in the highest esteem for this purpose are the Catalonian (Spain) and the Poitou (France).

The former has unusually good symmetry and action and reaches a height of 14 to 15 hands; the latter is a breed of great weight and substance and large bone, and is generally from 15 to 16 hands high. The females are about 2 in. smaller in each case. Other well-known breeds are the Maltese, the Majorca, and the Andalusian. Mules are preferred to horses both for farm and city work in warm climates. They are very sure-footed, and hence valuable as pack animals in mountain regions; they also possess great endurance and are not fastidious feeders. They are bred in great numbers in most Mediterranean countries and also in the warmer regions of both North and South America. Big mules can be bred only out of big mares. The offspring of a horse and a female donkey (hinny) has its fœtal growth restricted and remains undersized in after-life.



Farmer and Stockbreeder

A. Large White Boar



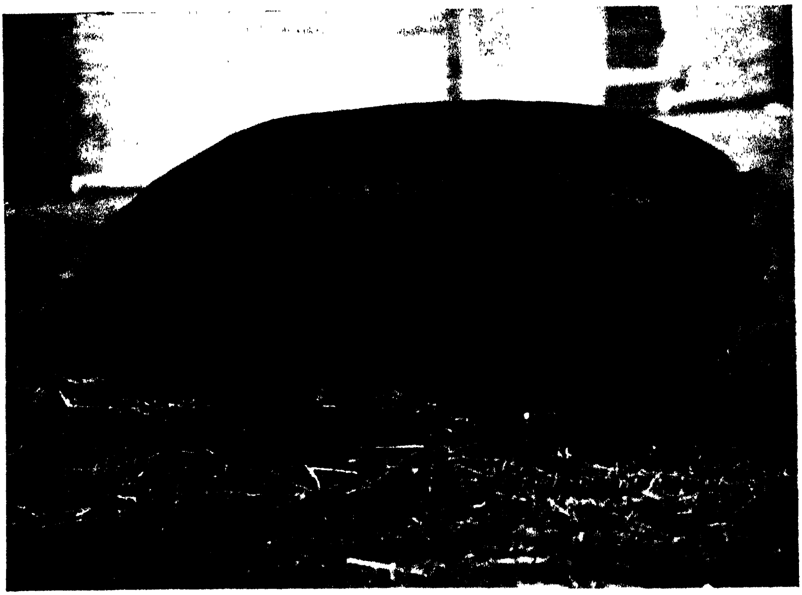
Farmer and Stockbreeder

B. Middle White Sow

PLATE LXII

Farmer and Stockbreeder

A. Berkshire Gilt



Farmer and Stockbreeder

B. Large Black Sow

CHAPTER VII

PIGS

THE pig belongs to the non-ruminant section of the Artiodactyls (even-toed hoofed animals). The wild pig is a forest animal, feeding upon acorns, beechmast and other seeds, roots, worms, grubs, and occasional small mammals. It consumes relatively little in the way of grass or other herbage. The digestive system is closely similar to that of man, except that there is more active bacterial digestion (of cellulose) in the large intestine. The wild sow normally farrows only once a year and the average litter is about four.

All our domesticated swine are believed to have descended from two closely related species—*Sus scrofa*, indigenous to Europe and North Africa, and *Sus vittatus* of Eastern and South-Eastern Asia. The latter is distinguished chiefly by its wider and shorter head.

The earliest known domesticated pig, *Sus scrofa palustris*, existed in Neolithic times, its remains being found along with those of the small short-horned type of cattle (*Bos brachyceros* or *longifrons*) and the small sheep of the same period. The domesticated pig of early historic times in Europe appears to have been closely related to the local wild type—long-legged with a long snout, heavy shoulders, short body, light hind-quarters, and a coat of coarse bristles. During Saxon times large herds were maintained, the animals being herded, for a considerable part of the year, in the widely prevalent oak forests. More recently pig-keeping was largely associated with dairying on the one hand and with corn growing on the other. On butter-making farms the traditional foods were skim milk, wheat offals, and barley meal, and on cheese farms whey, wheat offals, and beans. On corn farms the chief foods, as would be expected, were tail corn and millers' offals, supplemented by beans or peas. In either case the breeding sows and young animals, wherever conditions permitted, had a run on pasture in spring and on stubbles during autumn. Still later, pigs came to be associated with commercial potato-growing.

During the latter part of the eighteenth and in the early nineteenth centuries there was a considerable infusion of fresh blood by crossing with the so-called *Sus indicus*, introduced both directly from its home area in China and Siam, and indirectly through Mediterranean types, notably the Neapolitan. The Chinese differed from the native type in being smaller, shorter-faced, and very markedly earlier maturing—*i.e.* with a much more pronounced tendency to fatten while young. The admixture resulted in an animal that was smaller and less active than the indigenous type and easier to fatten, but of less fecundity. Among modern breeds the Chinese influence is most obvious in the Berkshire and Middle White, least so in the Tamworth and Large White.

Most of our present-day breeds have been evolved, or at least have been moulded into their present forms, within the past seventy or eighty years. Previous to the formation (in 1884) of the National Pig Breeders' Association there were no breed societies and no herd books. Up till that time breeding was conducted in a rather haphazard fashion, and although there were local types known as the Berkshire, Tamworth, Yorkshire, etc., their characteristics were very variable, and often widely different from those of the modern breeds that have inherited the names.

Pigs are, of course, valued almost solely as meat producers, but the meat may be utilized in different ways, and different types have been evolved to meet the varying requirements. Moreover, consumer demand and methods of utilization in Britain differ from those of most other countries. In the United States, for example, the hams, shoulders, and belly cuts are ordinarily cured, while the back and loin, after the removal of suplus back-fat, are marketed in the fresh state and retailed mainly as pork chops. In Britain, before the war, there were four main market types—viz.: (1) In the north, a relatively large and fairly fat pig, for bacon; (2) in the south, a lean and long pig of about 200 lb. live weight (or 150 lb. carcass weight), for the Wiltshire bacon trade; (3) "cutters" with a much wider weight range than that demanded by the Wiltshire curer. The method of utilization was to cure the hams and sometimes the forehams and belly cuts, and to sell the rest of the carcass as fresh meat; (4) the London porker, of about 70 lb. carcass weight, which was retailed as pork joints. In all cases trimmings and much of the edible offal

were normally converted into sausage, brawn, etc., while surplus fat was rendered into lard.

The weights mentioned above represent much less than mature weights—*i.e.* they are for animals still in active growth. Good specimens of the larger breeds, at maturity but in breeding condition, range from 300 to 400 lb. live weight in the case of sows, with boars about 100 lb. heavier. Exceptionally large animals, in very fat condition, reach weights of the order of 1000 lb.

Of all our farm animals the pig has the greatest capacity to accumulate body fat, more especially in early life. Hence early maturity, which is one of the chief objectives of the breeder of beef cattle and sheep, can, in the case of the bacon pig, be very easily carried to excess. It is therefore well that the selection of breeding stock, with the object of the right degree of early maturity, should be made when the animals have reached market weight—*e.g.* in the case of bacon breeds, at about six or seven months old. An animal which attains the desired body proportions at, say, five months old on normal feeding, will be too short and blocky, and will tend to yield an over-fat carcass when it reaches bacon weight.

The importance of the correct degree of early maturity is illustrated in Fig. 40. The typical Large White, slaughtered at 100 lb. live weight, yields a carcass with too much bone and too little fat, but when grown to 200 lb. gives a carcass of well-balanced proportions. The typical Middle White gives a good blocky carcass at 100 lb. but, at the higher weight, is too short, too heavy in the fore-end, and altogether too fat for any purpose.

It is, of course, possible, by restricted feeding in the later stages, to delay maturity and, by full feeding on a specially nutritious diet, to hasten fattening. But any major departure from normal feeding—more or less to appetite on a moderately concentrated diet—increases the food cost per pound of carcass weight.

The conformation desired in a pork pig, to be finished at four or five months of age, is comparable to that of a beef type of cattle or a mutton type of sheep. The highest-priced cuts are obtained from the back and loin (roasts and chops) and the ham (leg of pork). Hence a wide, thickly fleshed back and a heavy ham are wanted. At the age indicated pigs are still in rapid growth and, if fed on a well-balanced diet, are unlikely to be over-fat. In

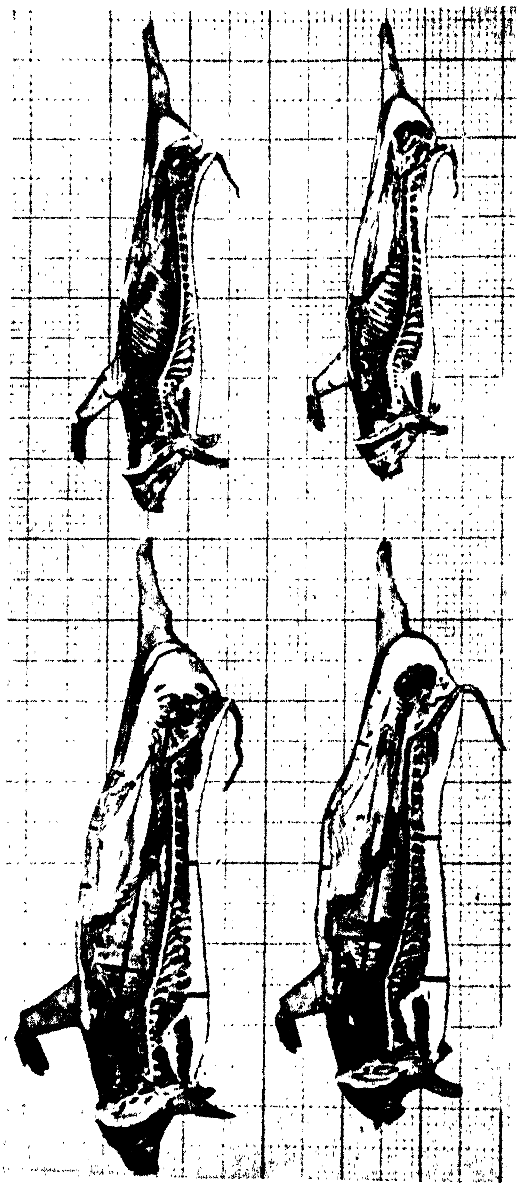


FIG. 40.—Carcasses of Middle White (right) and Large White (left) at 100 lb. live weight for Pork (top) and at 200 lb. live weight for Bacon (below)

the selection of breeding stock at porker weight a blocky conformation and thick fleshing should be the main criteria. Great length of body is incompatible with the degree of early maturity required.

The bacon type is longer bodied, rather higher on the leg, and more lightly fleshed than a pork animal of similar age. Since the side (back rashers and streaky bacon) and the ham provide the most highly priced cuts, great length, combined with a full, plump ham, are the main desiderata. The shoulder and jowl should be light. The side should be of uniform depth throughout and thick at the flank. In score-card systems of grading, length of body in relation to weight is emphasized, the other major points being a plump ham, a moderate thickness of back fat (1½ in. or not exceeding 2 in.), a thick belly wall (streak), and a light head and shoulder. The firmness and whiteness of the fat are also taken into account, soft carcasses being penalized; but the quality of fat is determined by feeding (see p. 761) rather than by breeding.

The distinguishing characteristics of the bacon and pork types are to some extent fixed in the various breeds. The Large White and Tamworth are essentially bacon breeds. The average type of Berkshire, being shorter, wider, and smaller of frame, is admirable for pork and useful for small bacon, but is unsuited to the production of full-sized bacon. Other breeds of intermediate type, with a certain amount of selection and appropriate management, can be successfully used for either purpose. The more important British breeds are arranged by Hammond in the following groups, but in some there is a considerable variation as between strains :—

Pork—
- Middle White.
- Berkshire.

Dual Purpose—
- Essex.
- Large Black.
- Long White Lop-eared.
- Wessex.
- Welsh
- Gloucestershire Old Spot.

Bacon—
- Welsh.
- Large White.
- Tamworth.
- Swedish Landrace.

Cross-breds are frequently preferred for commercial purposes. Thus the Berkshire × Middle White cross is admirable for small pork, while a dual-purpose sow—*e.g.* the Wessex—may be mated with the Middle White for pork or the Large White for bacon. The arguments for and against cross-breeding are set out later (see p. 752).

Apart from the special points desired for particular purposes, certain qualities are desirable under all circumstances. Robustness of constitution is one. Breeders of all classes of livestock tend to believe that " constitution " is correlated with certain points in conformation—for instance, a wide head or a capacious chest. In fact, there is no convincing evidence of any such correlation in the pig. Hardiness and thriftiness can be improved only by the continued weeding out of weakly animals or such as fail to attain a satisfactory rate of growth. Another requirement is sufficient strength of limbs to carry the body and to enable a reasonable degree of activity, which is very important in the breeding sow. The legs should be reasonably stout and fairly straight and the pasterns short and nearly upright. The temperament should be docile and quiet; nervous or savage or excitable animals are almost invariably unsatisfactory and, in particular, the temperament of the sow has much to do with the casualty rate among her young. Prolificacy is of obvious importance and, although there is a wide range of variation in the size of successive litters from the same sow, there is a considerable degree of heritability. Hence breeding animals of both sexes should be chosen from among the progeny of prolific dams.

The growth rate of the sucking pig during the first month of its life (a point of great economic importance) depends partly on its inborn capacity for growth but much more largely on the level of milk production of its dam. Hence sows whose litters bear evidence of poor nutrition should be discarded. Each pigling, within the first day or two after it has been farrowed, has its own teat; hence the maximum number that can be properly nursed is the same as the number of the dam's teats. In general, females should not be retained for breeding unless they have at least twelve well-formed and regularly spaced teats. Since teat number is inherited from both parents, the rudimentary teats of the boar should be examined with the same standard in mind. Gilts with ten teats, or even fewer, are not uncommon.

Most breed societies publish special registers of sows that have attained certain standards of performance in breeding and nursing—for example, an average for four successive litters, born within a period of twenty-two months, of eight piglings reared to weaning age.

Finally, colour is of some importance. On the one hand white breeds are somewhat liable to suffer from sun-scald when exposed to intense sunlight, though trouble of this kind is rare in Britain. On the other hand, black animals are liable to "seedy cut," *i.e.* the appearance of patches of dark coloration in the streaky rashers. The pigment can occur in the rudimentary mammary tissue of male pigs as well as in females.

Two procedures have been devised for the assessment of economic qualities in pigs and these should preferably be used in conjunction as guides to the selection of breeding stock. The one is known as *pig recording*, records made being of the number of young born in each litter, the number reared to the normal weaning age (eight weeks), and the individual weights of the piglings at that age. It is a useful refinement to record weights at three weeks of age as well as at eight, because the growth rate during the first three weeks is a measure of the milking propensity of the sow; subsequent growth is largely influenced firstly by the quality of the food (especially on the amount of skim milk or other milk products included), and, secondly, on the skill exercised by the pigman in inducing the piglings to "take to the trough" at an early age. Several pig-recording societies were operating in this country in the thirties, and plans had been made, at the time of writing, for developments on a national scale.

Official recording commonly ceases at weaning age, but the pig-keeper will be well advised to keep other records for his own guidance—of the age at slaughter of individual animals and of their carcass weights and carcass grades. The total food used, and the total live-weight increment of the herd, year by year, is a further useful measure of the overall efficiency of management. It is, of course, necessary to have a suitable weighbridge in order to arrive at the efficiency of food conversion even for the herd as a whole; but a weighing machine is a worth-while investment in any case since otherwise it is likely that individual animals, when sold, will fall outside the weight range to which the maximum price applies.

The other aid to improvement is *litter testing*, designed to assess the breeding value of individual boars. A reasonably accurate measure of a boar's merit can be obtained by selecting four of the heaviest weanlings (two gilts and two hogs) from each of three litters sired by him. The selected animals are moved to an official testing station, are kept under strictly controlled conditions, and are individually fed on a standard, balanced food mixture. Records are kept of food consumption, live weights at slaughter, carcass weights, and scores for carcass quality. The average food cost (in terms of pounds of meal per pound carcass weight) and the average carcass quality of the twelve progeny, taken together, constitute a good measure of the sire's breeding value. In theory the same progeny test can be applied to sows, but the dam will be of rather advanced age before the test results for samples of three litters can become available; the results from any much smaller sample of progeny would be subject to a large margin of error. Litter testing has long been in use in Scandinavian countries and has proved an important aid to improvement both in conversion efficiency and in carcass quality. Litter-testing stations have recently been set up by the (British) National Pig Breeders' Association.

Until fairly recent times the ordinary basis of selection of breeding stock has been visual inspection, either by breeder or prospective buyer or show judge. Breed societies have recently, however, required members to provide returns of numbers born and reared in every litter from which any pigs are to be registered. It is thus possible to build up an extended pedigree of any animal, with all the evidence of the prolificacy of its female ancestors and of their ability to rear their young.

BRITISH BREEDS

There are, besides a few of small and purely local importance, eleven recognized British breeds, each with its own pedigree record. The Berkshire, Large White, Middle White, Large Black, Tamworth, Welsh, and Gloucester Old Spots are under the care of the National Pig Breeders' Association, while the Essex, Long White Lop-eared, and Lincolnshire Curly Coated have each their separate societies.

The Large White (or Large Yorkshire) (Plate LXI, *A*) is derived from an early North Country type, large in size and

either all white or white with black spots. Probably it contained very little Chinese or Neapolitan blood. The evolution of the modern breed began, before 1850, in the industrial districts of the West Riding of Yorkshire, the pioneers being largely factory workers. In 1851 a weaver of Keighley, Joseph Tuley, exhibited at the Windsor Royal Show a pig of the improved type which attracted much notice.

The Large White is a pig of great size, being exceeded only by the Lincoln Curly Coat. Mature boars reach 7 cwt. in good breeding conditions and up to 10 cwt. when fully fattened. The head is of medium length and "dished," but the nose is not turned up. The ears are of medium length and incline forward but are rigid. The skin is fine and carries a moderately abundant coat of silky hair. The breed standard calls for pure white skin and coat, but occasional animals show small patches of dark skin and, more rarely, of black hair. The general conformation is that described for the bacon type—light in head, jowl, and shoulder, with great length of body, moderate depth of side, and plump but smooth hams. Broadly speaking, growth continues long and maturity is relatively late, but in this respect there is some variation as between strains. All strains can produce a first-class bacon carcass at the age of six to eight months, and some are quite suitable for the production of medium-weight porkers. All but the best types are somewhat inferior, in bacon conformation, to the Danish Landrace, which has been bred systematically for bacon quality for many years.

The Large White is, according to available records, the most prolific of all our breeds, the average number born per litter being over ten. But the sows are sometimes less docile than could be wished, so that losses of piglings, in the first few days of life, are higher than in certain other breeds. Milk production is good, and the young grow rapidly.

The Large White is widely distributed over Great Britain and Ireland, with some concentration in the north and east. It has been largely exported to other bacon-producing countries, including Canada and New Zealand, and has been used in the formation of many overseas breeds.

The Middle White (Plate LXI, *B*) was formed by the blending of the blood of the Large White with that of the now extinct Small Yorkshire, which latter was a small, short-faced, fine-boned, and excessively fat animal, such characteristics

reflecting the very high amount of Chinese blood that it carried. The Middle White was recognized by the Royal Agricultural Society in 1882, but the type was not fully fixed until twenty years later. Sanders Spencer, of Holywell, St Ives (Hunts), played the leading part in developing the breed.

In weight the Middle White is about 20 per cent. less than the Large White and is probably the smallest of our breeds, though but little below the Berkshire and the Tamworth. The head is short, dished, and the snout turned up; the ears of moderate size and carried erect; the jowl is sometimes heavy and the general build is rather short, wide, and compact; the breed is low-legged and the coat is thicker than in most other breeds. The Middle White, maturing very rapidly, formerly shared with the Berkshire the trade for small porkers, and the decline in its numbers is to be explained by the disappearance of this market. The modern tendency has been to breed for greater length of body, a lighter shoulder, and a leaner type of carcass. The sows are less prolific than those of the Large White, and the growth rate of the young, as would be expected, is less. Boars of the breed are useful for cross-breeding with sows of the larger and leaner breeds, and have proved very valuable overseas in the grading up of unimproved stock.

The Berkshire (Plate LXII, *A*) originated, as its name implies, in the Thames Valley. Culley, writing in 1789, describes Berkshires as " generally reddish brown with black spots . . . large ears hanging down over their eyes, short-legged, small-boned, and exceedingly inclined to make rapidly fat "; but other descriptions vary widely from this, and it seems that there must have been a great diversity of types. The modern breed is of a rather rusty black colour, with white " points "—tail, face, and feet. It is, according to Smithfield weights, slightly heavier than the Middle White. It is smaller-framed than the Tamworth but about as heavy. The head is rather short but the snout is not turned up. The ears are rigid but incline forward. Body conformation is similar to that of the Middle White, but the hind quarter is typically more level. The Berkshire is less prolific than the larger and longer breeds and the young sometimes make slow growth in early life.

The outstanding merit of the Berkshire is the quality of its meat at the small-porker stage of development. At one time pure-bred Berkshires were supreme in the Smithfield pork-carcass

competitions, but the breed has suffered, like the Middle White, by the loss of its special market. Abroad, the Berkshire is widely popular, its dark colour being an advantage in sunny climates. The types developed in the United States, Canada, and Australia are generally longer bodied and leaner than the original.

The Large Black (Plate LXII, *B*) is an old breed which came into prominence only after the founding of its Breed Society in 1899. The foundation stock came partly from Cornwall and Devon and partly from Suffolk and Essex, but the original differences in type have long ago been eliminated. The breed is widely distributed in Britain and has been largely exported, especially to warmer countries.

Animals of the breed reach weights only slightly less than Large Whites of comparable age. The head is of moderate length, the ears long and lopping, the tips reaching to the nose. The hair is jet black, fine, and generally rather abundant, but the skin is not deeply pigmented. The general build is intermediate between that of the Large White and Tamworth on the one hand and the Berkshire and Middle White on the other; in other words, the conformation is that of a dual-purpose animal. The shoulder is notably light in relation to the ham, but the flesh is often less smooth than that of the Large White. The sows are remarkably docile and seem to be able to build up bodily reserves, during pregnancy, with very little food other than good grazing. The average size of litter is about nine as compared with ten for the Large White, but the casualty rate is substantially less. The Large Black sow, crossed with the Large White boar, gives a product with much of the bacon quality of the sire and a mainly white coloration, and which has the advantage of the good "mothering" ability of the dam.

The Tamworth (Plate LXIII, *A*) has its home in the Midlands, particularly the district about Birmingham. It is of comparatively small weight, long-bodied, and relatively narrow in build, with a very long straight snout and red (chestnut) colour. The breed was at one time reduced to small numbers, and prolificacy (probably through in-breeding) declined seriously, but importations from Canada have helped to restore fertility and vigour. The Tamworth is slow-maturing, but its long smooth side, neat shoulder, and firm flesh makes it very suitable for the production of high-quality bacon.

The Wessex Saddleback (Plate LXVI, *A*) and the **Essex** (Plate LXVI, *B*) are of similar type and colour—black with a white " saddle " over the shoulders and forelegs. The Essex breed-standard calls for white hind feet and a white tip to the tail, whereas in the Wessex the hind feet and tail should be black. Both breeds are liable to produce a proportion of all-black individuals, the probable explanation being that the wide-belted and all-black types breed true, while the animals with narrow belts are often heterozygous—*i.e.* they throw wide-belted, all-black, and narrow-belted progeny.

The ears are of medium size, with a forward pitch, but rigid. They have more forward inclination in the Wessex. Both breeds are hardy and the sows milk well. The Wessex is slightly the larger.

The Saddlebacks are, after the Large White, the most numerously represented breeds, and the cross between the Large White boar and the Saddleback sow is very popular with commercial breeders. The statistical evidence on prolificacy is to the effect that, although the Wessex has a lower average number of pigs born per litter than the Large White, the average number weaned is slightly greater.

The Gloucester Old Spots (Plate LXIII, *B*) is an old local type which was little known until the establishment of a herd book in 1914. In conformation it approaches the Large White. The pig is hardy, prolific, and a good grazer.

The Lincoln Curly Coat (Plate LXIV, *A*) is larger than the Large White, more heavily fleshed, and rather coarser in bone. The coat is abundant and curly. **The Swedish Landrace** (Plate LXIV, *B*) is of extreme bacon type, very long-bodied and light in shoulder. The face is medium long and the ears incline forward. **The Long White Lop-eared** (Plate LXV, *A*) is, apart from colour, closely similar to the Large Black. Its home district is Devon and Cornwall. **The Welsh** (Plate LXV, *B*) is similar, but rather longer and leaner in build. It is gaining in popularity by reason of its hardiness and good carcass qualities.

There is an almost complete unanimity that the number of British breeds is unnecessarily large. The needs of the industry could probably be met by half the present number—two bacon breeds, perhaps two dual-purpose types selected for prolificacy and mothering ability, and an early-maturing pork breed.

All boars are required to be licensed by the Agricultural

Departments. The following table, giving the number of new licences issued in the last year for which figures are available, indicates the relative importance of the various breeds :—

Breed	England and Wales, 1954	Scotland, 1953	Northern Ireland, 1953
Berkshire . . .	101	...	...
Large White Yorkshire .	19,051	1800	960
Middle White . . .	125	...	...
Tamworth . . .	102	8	...
Wessex Saddleback . .	1,371	210	...
Cumberland . . .	5	...	4
Essex	1,031	34	...
Gloucester Old Spots .	58	...	...
Large Black . . .	620	91	...
Long White Lop-eared .	55	...	...
Welsh	985	...	...
Landrace . . .	251	...	...
Yorks Blue and White .	6	...	...
Oxford Sandy and Black .	2	...	...
Other Breeds . . .	14	3	...
Total . .	23,777	2236	964

BREEDING

Well-grown and liberally fed gilts begin to come on heat at the fifth or sixth month of age, and from this time until they are large enough for mating they should be kept apart from boars. The minimum age for breeding, for good results, is about eight or nine months in the case of the female. But the actual criterion should be size, and a body weight of about 175 lb. in store condition may be taken as a reasonable standard. Earlier mating often results in an unsatisfactory first litter and may cause permanent stunting of the sow's growth. Some breeders prefer to delay mating to an age of ten or even twelve months. Young boars (brawns) may begin to serve at seven or eight months of age.

The female comes on heat, except when pregnant or nursing, at intervals of twenty to twenty-one days throughout the year, so that it is possible to arrange for litters to fall at any season. Œstrus is rare while a sow is in milk, but occurs very soon after her litter has been weaned, very commonly on the third or fourth day. The period of heat lasts forty to sixty-five hours, and the

onset is heralded, some two days in advance, by a swelling and reddening of the vulva. Ovulation occurs towards the end of the heat period, so that sperm from a service soon after the onset may have lost its vitality before the eggs are shed. The ordinary rule is to mate during the second day of œstrus and, in case the sow is still on heat the following day, to mate a second time. It should also be borne in mind that the first service from a young male, or from one that has been rested for some time, may be ineffective because of the inactivity of the sperm. In this case a second mating should follow a few hours after the first. Except under these exceptional circumstances there is nothing to be gained by mating twice during the same œstrous period. Sows are more likely to conceive at the first heat after weaning than at subsequent heats.

Since the gestation period is sixteen weeks (varying only a day or two one way or the other), and since litters are normally weaned at eight weeks of age, the breeding cycle is completed in just under six months. Some sows, in fact, farrow at half-yearly intervals throughout their breeding lives, but the average interval between litters is between six and seven months.

It is sometimes argued that eight weeks is too early an age for weaning, but it must be recognized that the period of lactation of the sow is very short. In most cases the peak milk yield is reached about three weeks from farrowing, and the milk flow has commonly dropped to a low level by the eighth week. A surer method of preventing a set-back at weaning than that of extending the suckling period, is to induce the young to begin eating at the earliest possible age, and to use specially nutritious food during the suckling period and for a few weeks after weaning.

In large commercial herds, provided with adequate housing, the usual aim is to have the farrowings evenly distributed throughout the year and so to achieve a regular flow of marketable pigs. Any other system makes for periodic congestion of housing and to fluctuating demands for labour. But if the available buildings are poorly insulated, damp, or otherwise unsatisfactory, farrowing in the dead of winter is best avoided.

The useful life of a sow may ordinarily extend to four or five years or, say, six to eight litters. But since there is always a wide choice of gilts for replacement, sows that have proved unsatisfactory should be discarded after one or two farrowings. Specially valuable pure-bred sows may be retained till an age

of eight or even ten years, though they generally become progressively less prolific after their fifth year. Individual litters vary from one or two to more than twenty, and the average reaches about ten in the more prolific breeds. With first-class management numbers reared can reach an average of nine per litter or eighteen per year, but a figure of seven per litter, with an average interval of seven months between successive farrowings (giving an output of twelve progeny per sow per year), can be taken as satisfactory under the conditions of commercial farming. Gilts' litters tend to be one or two less in numbers than those of sows in their prime, but something depends on the age at first mating.

Very large litters are not desirable. More than twelve should not be left on a sow since, even if she has fourteen functional teats, the hindmost pair usually give very little milk. Many breeders limit numbers to ten for sows and eight for gilts, but with good stock and good management twelve and ten respectively may be permissible.

Surplus piglings, if healthy and vigorous, may be easily transferred to another newly farrowed sow, with a small litter of her own, if such happens to be available. A sow will commonly raise no objection to foster-piglings, even if these are of a different colour from her own. If no foster-mother is available the surplus pigs (being, of course, the poorest of the litter) must be killed; action, however, should be delayed until about the third day after farrowing, since most casualties occur during the first two or three days.

As regards systems of breeding, the simplest is, of course, to select a particular pure breed and to aim at progressive improvement by selection, with such aids as pig recording and litter testing or, at the least, by turning to account all the data about prolificacy, efficiency of food conversion, and carcass quality that can be got together. This is the system that has been applied with marked success in Denmark.

Many commercial producers in this country prefer a system of crossing. Where the process is confined to first crossing, the plan is that the sows should be of a breed combining prolificacy, milking ability, and "mothering qualities" with reasonably good conformation—*e.g.* the Wessex—and to cross with a boar likely to be prepotent for growth rate and carcass quality—normally the Large White.

Apart from the advantage of combining the desirable qualities of the two parents there is the argument that first-cross animals

are more vigorous and faster growing than pure-breds—*i.e.* that crossing, as such, results in hybrid vigour. The experimental evidence in support of this contention is not very conclusive, a fact that may be explained on the assumption that hybrid vigour depends on the heterozygous condition of certain particular pairs of genes, and that it will be largely a matter of chance whether a cross-bred animal will be more heterozygous, with respect to the factors concerned, than a pure-bred.

Sometimes crossing is carried a stage further with the object of taking advantage of hybrid vigour in the sow. Thus one might cross the Large White with the Wessex, and mate the cross-bred females back to the Large White. Going still further, some American commercial producers follow a system of rotational crossing, using three breeds. Breed A is mated to breed B, the cross-bred sows to a boar of breed C, the produce of the last to a boar of breed A, and so on.

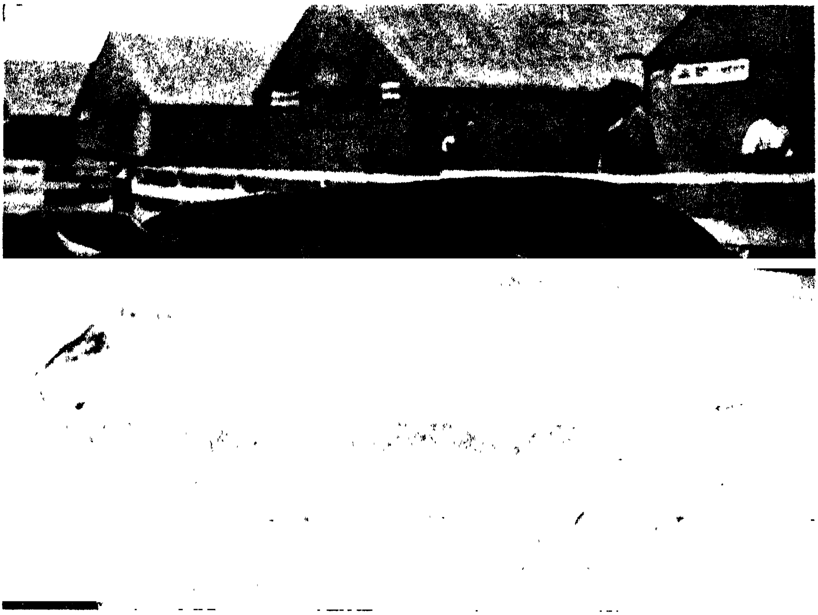
The obvious objection to all systems of cross-breeding is that either two pure breeds must be maintained or, alternatively, that the breeder must rely on others for a continuing supply of pure-bred gilts as well as of boars. In the latter case he cannot himself follow any system of progressive improvement.

Where the decision is in favour of a single pure breed, there remains the question of the degree of inbreeding that should be adopted; the matter is discussed in Chapter I of this section.

Still another system, also discussed in Chapter I, aims at the production of highly inbred families, in each of which the least desirable genes have been bred out, and then crossing up two or more of these families for the production of commercial stock—*i.e.* the same technique as is used for the production of hybrid maize. The process has been carried near to completion in the United States, and the production of inbred families is proceeding under the Animal Breeding Research Organization at Edinburgh.

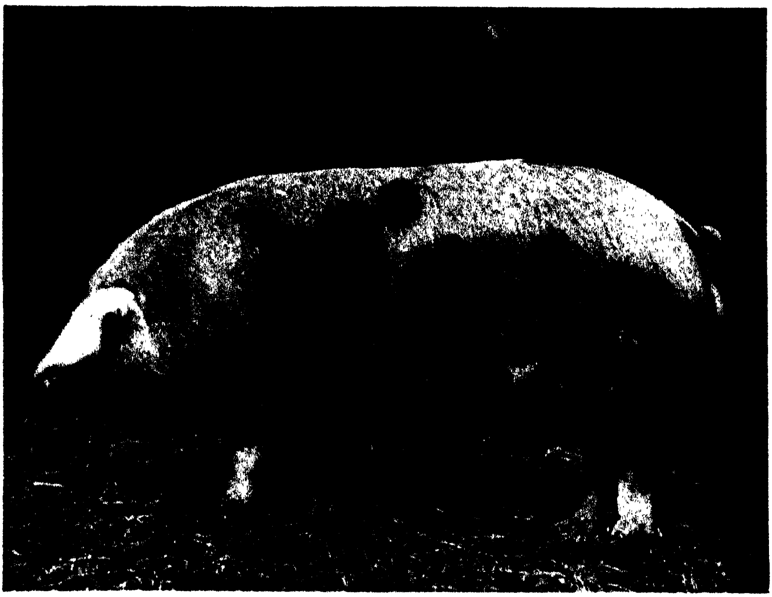
SOME PRINCIPLES OF HOUSING

There is a great variety of housing systems for pigs. The choice depends on a balance of considerations, having regard to the local climate, the soil type, the size of the enterprise, and the available supply of capital and labour. The major objectives should be: (1) The provision of environmental conditions that will conduce to full health and vitality—warmth, comfort, and



Farmer and Stockbreeder

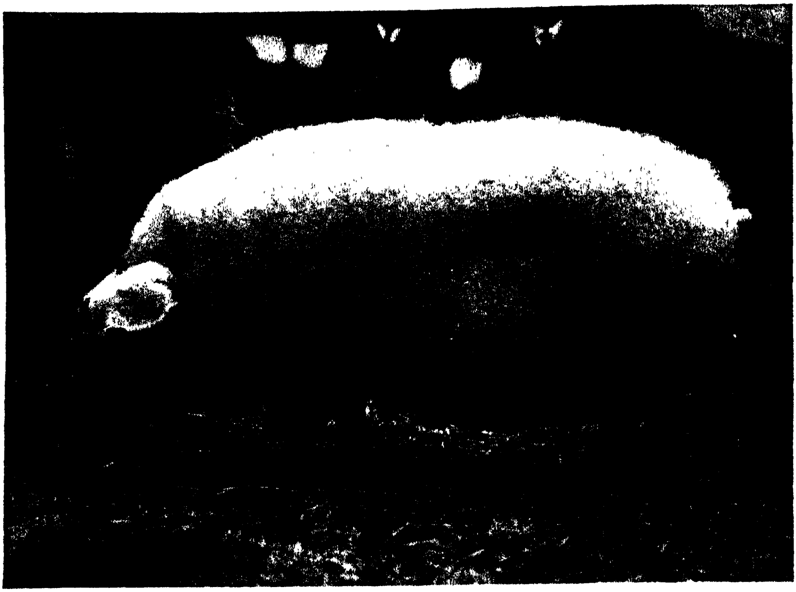
A. Tamworth Boar



Farmer and Stockbreeder

B. Gloucester Old Spots Sow

PLATE LXIV



Farmer and Stockbreeder

A. Lincoln Curly Coated Sow

Farmer and Stockbreeder

B. Swedish Landrace Gilt

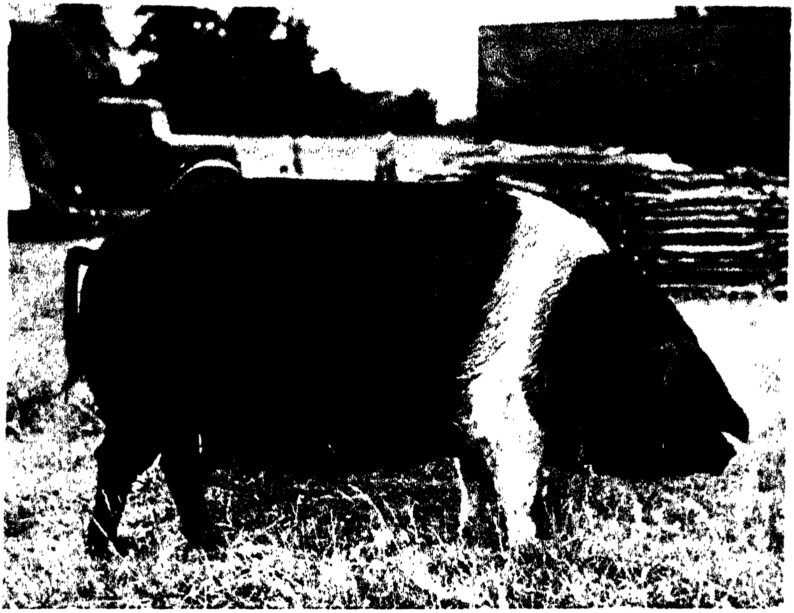
Farmer and Stockbreeder

A. Long White Lop-eared Sow

Farmer and Stockbreeder

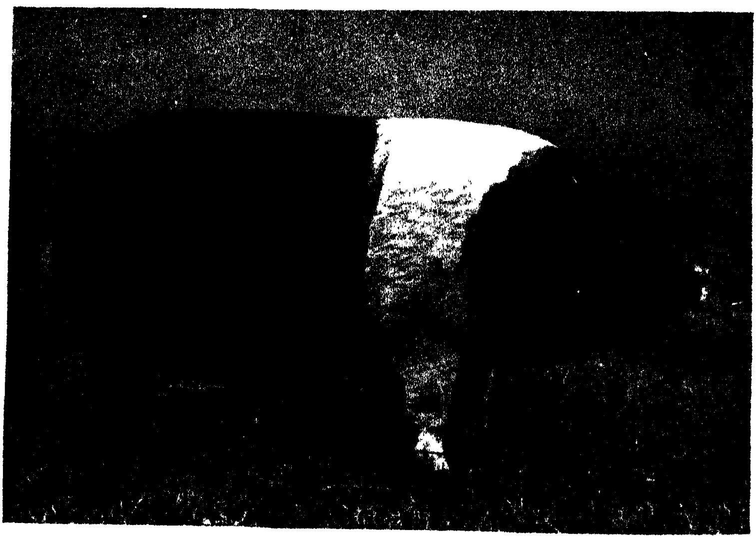
B. Welsh Gilt

PLATE LXVI



Farmer and Stockbreeder

A. Wessex Saddleback Sow



B. Essex Sow

opportunity for the necessary minimum of exercise; (2) the control of parasitic infestation and contagious disease; (3) the prevention of nutritional disorders—especially piglet anæmia; (4) reasonable capital cost; and (5) economy of labour.

No system so far devised can be said to be the best under all circumstances and in all respects, and decisions must be reached on a balance of considerations.

1. The pig, being a forest animal in nature, and thus having opportunity to seek shade in hot weather and shelter in cold, has a narrow range of tolerance in regard to environmental temperature. It should be remembered, too, that high air humidity intensifies the adverse effects both of heat and cold. Animals in show condition are subject to " heat stroke " and young pigs are very susceptible to cold. The commonest fault in farrowing sheds is that they are too cold in winter. A condition that has, in the past, been confused with piglet anæmia has been closely associated with chilling, due either to too low an air temperature (sometimes combined with high humidity) or to poorly insulated flooring. The optimum environmental temperature for a baby piglet, at rest, is probably about 80° F., a level that can be maintained inside a well-strawed nest in a building with an air temperature of about 65° F. and with a well-insulated floor. Where the air temperature is liable to fall below 65° some form of artificial heating for the nest should be provided. One possibility is floor heating by means of resistance wires; another is an electric heat-lamp suspended about 2½ ft. above the nest; or, failing a supply of electric power, an oil lamp. Space heating, by stoves or hot-water pipes, is unsatisfactory, because (apart from its high cost) high temperature throughout the building results in a high rate of ammonia production from urine.

All this may be thought to be at variance with the experience that piglets generally do well, even in winter, in the common type of simple wooden hut, of triangular section, with free access to the open; but it has been shown that the temperature maintained at the back of a well-bedded hut is generally much higher than that prevailing in a permanent farrowing shed with the usual amount of air-space and the common amount of ventilation.

Casualties in cold buildings are due either directly to chilling or indirectly through the tendency of the young piglets, in the absence of any other source of warmth, to crowd round the sow and thus to risk being overlaid.

Where existing buildings have poorly insulated floors, a sleeping platform of wood or other non-conducting material may be provided. If the air-space is excessive a ceiling may be added at a convenient height.

A useful check on the adequacy of the temperature in the farrowing quarters is the seasonal variation in piglet casualty rates and in average weaning weights. Thus, if, in summer, the piglet death-rate is 5 per cent. and the average weaning weight 35 lb., and if the corresponding winter figures are 15 per cent. and 26 lb.—a not uncommon relationship—the likely explanation is that the farrowing quarters are too cold.

Cold tolerance, of course, increases with body size but also depends on bodily condition, since the layer of back-fat acts as a blanket. Warmth continues to be of importance in piglets at the post-weaning stage and also in the case of sows in very reduced condition following lactation. Given a dry bed, well-grown stores and mature animals, in good condition and run in sizable groups, require no special consideration.

As regards exercise, breeding sows during pregnancy, breeding boars, and gilts intended for breeding require a fair amount of freedom and should either be kept in yards or have an outdoor run. Stores and fatteners will generally get all that they need in sties.

Trough room is important both in order to ensure that all pigs in a group have equal opportunity to feed but also because over-crowding at meal-times may lead to fighting. One foot per head is the common allowance for pigs up to bacon size, but the optimum is probably rather more.

A very important measure is the provision of a " creep " in the farrowing pen, so designed as to keep out the sow and admit her young. Food, preferably in the form of pellets or small " nuts," should be offered in the creep from the age of three weeks.

Considerations of general comfort are important in relation to the choice between the indoor and outdoor systems. On free-draining light land, a good sward can with ease be maintained in pig paddocks, and young pigs benefit from outdoor exercise. But with poorly drained soil in a wet climate the pen soon becomes a quagmire and so much mud is carried into the huts that it is impossible, in practice, to keep the interior dry.

2. As regards parasites, the most prevalent types—the lung

worm, the round worm of the intestine, and the stomach worm—are very liable to be picked up from contaminated ground, and unless the animals are frequently treated, fixed paddocks rapidly become "pig sick." Moreover, a sward stocked entirely with pigs deteriorates rapidly so that there is little grazing. Moreover, the manure is then largely wasted. Hence permanent runs have to be periodically rested from pigs—*i.e.* must be stocked with some other type of animal.

The system greatly to be preferred is one in which the whole installation is moved at intervals of a few months to a fresh site with a clean and well-established sward.

There are three possible modifications of the hut-and-run system. The one employs a fold unit—*i.e.* a hut with an attached unroofed pen, mounted on wheels or skids, which can be moved to clean ground at intervals of a few days or even daily. Under another system the sow is tethered by means of suitable harness and chain to a peg which is driven into the ground a few yards from the entrance to the hut, the young pigs being allowed free range over the pasture. A third is to confine the sow, by means of an electric fence, to a small area surrounding her hut, the height of the wire being, of course, sufficient to allow the piglets to range outside.

The wide dispersal of pigs under the outdoor system is a favourable factor in relation to the spread of certain contagious diseases. This is not true of swine erysipelas, which is caused by an organism that can live in the soil. In any case this trouble, as well as swine fever, can be controlled by immunization. Virus pneumonia (pig influenza), however, since the infection can be air-borne, is much more prevalent under the indoor system—at least where farrowing is carried out in a building that accommodates a number of litters.

3. The commonest nutritional disorder is piglet anæmia, associated with a low iron content in the blood. The danger arises from the fact that iron is virtually absent from sow's milk, so that the piglet, though born with a certain reserve, soon becomes dependent on some other source. Green herbage and soil are the natural sources, so that piglets with access to the land are never affected. Moreover, if the pregnant sow spends part of her time out of doors, the piglings, at birth, will have considerable reserves. Under the indoor system the trouble can often be prevented firstly by feeding greenstuff to the sow during pregnancy,

and secondly by placing a fresh turf, or a spadeful of soil, in the farrowing pen daily. In other cases it is necessary to resort to dosage of the piglings, in their second week, with iron salts.

4. The prime cost of housing is, of course, greater in the case of a permanent building than that of movable huts, together with pig fencing for the surrounding paddocks. On the other hand, the rate of depreciation on the latter is much the higher.

5. Labour costs are reduced by concentrating pigs in large groups, with well-planned arrangements for feeding and the removal of dung. The feeding of scattered groups involves a large expenditure of time. Moreover, it is very difficult to achieve the proper degree of supervision, particularly of farrowing sows, if these are in dispersed individual huts over a large area.

A few miscellaneous points may be added.

Some breeders are accustomed to use farrowing crates in order to restrict the movements of the sow and prevent the young being trodden or overlaid, but it seems that the desired result can generally be achieved by providing a warm nest to which the sow has no access. Opinions differ as to the value of farrowing rails, which have the object of saving piglings from being caught when the sow lies down against the wall of her sty.

While strong pig-netting is necessary to confine a boar, breeding gilts and pregnant sows, running in groups, can be controlled by an electric fence.

The usual size of farrowing huts is 8 by 10 ft., while indoor farrowing sties should ordinarily be 10 by 10 ft. Where a number of farrowing or feeding pens are grouped together in the same building, each, as a precaution against the spread of disease, should have independent drainage.

The housing system need not be either a purely indoor or a purely outdoor one. One popular arrangement is to have a block of farrowing pens in a permanent building with small runs to which the animals are given access for a short period every fine day; to have a yard or two, opening on to a large paddock, for breeding gilts and in-pig sows; to use an all-indoor fattening shed with a series of pens of varying size, so that groups of weanlings, as they grow, can be moved from the smaller to the larger, while backward pigs, when their sty-mates have gone for slaughter, can be placed in the small pens. Re-grouping should be avoided, so far as possible, since this leads to fighting. Sows in very reduced condition at weaning should be

kept by themselves until they have fully recovered strength and activity. Such needs should be foreseen in planning.

FEEDING

It must be borne in mind that the digestive organs of the pig are of a very different type from those of the purely herbivorous animals. The capacity of the alimentary canal is, in proportion to the size of the animal, about half what is found in the ox, sheep, or horse. There is no provision, such as is made in the paunch of the ruminant or the cæcum of the horse, for holding a large quantity of bulky, fibrous food while it undergoes bacterial digestion. Despite the smallness of its digestive tract the pig, on full diet, eats more, in relation to its size (and in terms of dry matter), than other farm mammals. This implies that the process of digestion is much more rapid. Bacterial digestion does occur in the large intestine, but this is capable of dealing with only a small amount of cellulose. Hence the proportion of fibre in the diet must be kept low.

While cellulose digestion is much less efficient than in the ruminant, the more readily digestible materials—starch, sugar, and protein—just because they are not subjected to bacterial action, are more efficiently utilized by the pig.

The pig's capacity for growth and fattening is remarkably high since its high energy intake is coupled with a maintenance requirement that is not substantially greater than those of the other farm animals. A steer of 9 cwt., on full feed, consuming 25 lb. of dry matter, with some 13 lb. of starch equivalent, may make a daily live-weight increase of about 2 lb., whereas a pig of 200 lb. weight, on a ration providing 6 lb. dry matter and about 4½ lb. starch equivalent, may be expected to gain about 1½ lb. per day. Moreover, the proportion of carcass weight to live weight is substantially higher in the pig. Such comparisons must not indeed be pressed too far, since the steer can utilize straw, hay, pasture grass, and other cheap, bulky material in relatively large quantities.

In general, if the pig's capacity as a converter of feed into meat is to be fully exploited, its rations must provide a large quota of energy in small bulk. It is only in the case of the pregnant sow or the full-grown boar that the concentrate can be economically cut down by any large amount and replaced by

grass or green food. Considerable use can, however, be made of roots, especially potatoes and fodder beet, since these contain only small amounts of fibre.

The fact that pigs require a highly concentrated diet has led, at times, to serious mistakes in feeding. The traditional foods—barley meal and wheat middlings—are poor in regard to both the quantity and quality of their proteins and have a very unsuitable ash balance—a deficiency in calcium, an excess of phosphate, and a shortage of common salt. The traditional supplement was skim milk (or, alternatively, whey with beans or peas), and when this was used in adequate amounts good results were obtained.

Young pigs—up to the age of four or five months—make maximum growth only if they have a proportion of animal protein in their diet; the usual sources are white-fish meal, meat meal, meat-and-bone meal, and separated milk either in liquid form or dried. Skim milk appears to have some special merit in promoting health and growth. After the age indicated, quite satisfactory growth and development can be obtained on rations containing vegetable proteins only. The oil-content of the ration should be kept fairly low, especially in the later stages of fattening, in order to avoid the carcass fault of soft fat. Unsaturated oils are particularly objectionable, so that herring meal should be used in small amounts only. White-fish meal and meat-and-bone meal contain substantial amounts of calcium, so that, when used in considerable amounts with a moderate amount of clover or other greenstuff, the addition of minerals may be unnecessary. Most proprietary pig meals contain added minerals, often in great variety; but it seems that, in at least the vast majority of circumstances, it is sufficient to add about 1½ per cent. of ground chalk and ½ per cent. of common salt to the meal mixture.

Iron deficiency, as mentioned earlier, is the cause of nutritional piglet anæmia, which may develop in cases where the piglets have no access to soil before they begin to take solid food—*i.e.* during the second and third weeks of age. The symptoms are commonly most severe at about the tenth day. It can be prevented by administering daily, during the second week of life, a small dose of ferrous sulphate. A convenient method is to dissolve 3 oz. of ferrous sulphate in half a gallon of water and add half a gallon of molasses, and to dose at the rate of a teaspoonful per day.

As regards vitamins the only likely deficiencies will be of

A and D_3, the former only where insufficient greenstuff is fed, and the latter only in animals that get little or no direct sunlight or "sky-shine." In case of doubt on either score, about 1 per cent. of cod-liver oil may be added to the mash once or twice a week.

The total energy value of the food, in relation to its dry-matter content, is of obvious importance. For growing and fattening animals and for lactating sows the starch equivalent should be about 75 per cent. of the dry matter, or about 65 per cent. on an air-dry basis. Sucking pigs and those newly weaned should have a rather more concentrated diet—say, a mixed meal with a starch equivalent of perhaps 68. For pregnant sows and growing gilts a figure of 55 will suffice, this being ordinarily arrived at by feeding a limited amount of meal along with grazing, or with greenstuff such as kale, cabbage, clover, or roots. With good clovery pasture only a small allowance of concentrate is necessary.

The protein balance should be varied according to the age, etc., of the animal. The young pig (up to the age of about four months) and the nursing sow have high requirements—a ratio of protein equivalent to starch equivalent of about 1 : 5, or, in other words, about 13 per cent. protein equivalent in the mixture. Thereafter the protein equivalent may be reduced to about 11½ per cent. and finally, in the later stages of the bacon pig's life, to about 10 per cent.

The following are examples of mixtures suitable for the three groups in a breeding and feeding herd :—

	I Nursing Sows and Weaners	II Growing Pigs 3 to 5 months	III Over 5 months of age
White-fish meal	7	4	...
Bean meal	7	9	13
Barley meal	25	30	35
Flaked maize	25	25	20
Weatings (Middlings)	35	30	30
Minerals	1	2	2
Starch equivalent	68	67	67
Protein equivalent	13	11·5	10

A variety of ready-mixed foods are, of course, available on the market, either as meals, feed nuts, or pellets; and where the requirements for a particular group of pigs are small there is a

strong argument, on grounds of convenience, for their use. Where home-grown and purchased foods are used together, it is obvious that the mixture should be balanced. Too often a purchased compound is supplemented by tail-corn or potatoes, when, of course, the protein balance is seriously altered.

The "creep" feeding of sucking pigs is discussed later (see page 764).

A common variation of all-meal feeding is to use a mixture like No. II above up till the point where consumption reaches 3 or 3½ lb. per day and thereafter to keep the meal ration constant, adding boiled potatoes, sliced fodder-beet, or sterilized household swill to appetite. Since all these materials have a low protein-content, the overall nutritive ratio of the combined ration falls progressively with the proportion of meal to other materials. This scheme is known as the Lehmann system, after the German worker who devised it.

As already said, pigs should have a small daily allowance of green food, either in the form of pasturage or kale, green clover, etc. In the absence of a supply a small amount of dried grass may be incorporated in the meal, or be fed in the form of grass nuts.

Under many circumstances, it appears that the incorporation of a small amount of antibiotic material—usually aureomycin or procaine penicillin—increases growth rate and the efficiency of food conversion. Typical results are 10 per cent. faster growth and 5 per cent. improvement in conversion. The main explanation appears to be that the bacterial flora of the digestive tract are controlled and minor digestive upsets are thus prevented, but the precise mode of action was not understood at the time of writing.

With regard to the preparation of the food, all hard grains must be either ground or soaked, otherwise they may escape digestion. Experiments in the feeding of dry meals (as against a thick slop) have shown no constant or important differences, but there is more risk of waste by dry feeding. Except for the farrowing sow, the slop should be of thick consistency, especially in cold weather. If dry meal or a thick slop is used, water, if not provided in drinking bowls, should be offered twice daily; but with a mixture of one part meal to two parts of water (by weight) it is generally found that pigs will drink only during periods of hot weather. Cooking should not be done except in the case of potatoes (whose starch grains in the raw state tend to escape digestion) or in that of materials of doubtful soundness.

Household swill must, by law, be cooked as a precaution against foot-and-mouth disease.

Where pigs are intended to be fed to appetite, the dry meal may be offered in self-feeders, of which several types are procurable, water being provided from troughs or drinking bowls. In general, growing pigs are frequently given all that they will eat, and there is little or nothing to be gained by restriction. On the other hand, breeding gilts and pregnant sows will get much too fat unless the concentrate is restricted; moreover, it is generally economical to compel them to consume a large proportion of grass, greenstuff, roots, etc. Again, all but the more extreme types of bacon pigs tend to get too fat to command the best price if, in the last month or two, they are fed *ad lib.*

During the last few weeks of the bacon pig's life the effect of feeding on the quality of the carcass should receive consideration. On the one hand, excessively watery foods—roots, whey, or distillery paste—should be fed only in moderate amounts. On the other hand, materials that contain any considerable amount of unsaturated oil should be avoided as likely to produce soft carcass fat. Examples are maize germ meal and, to a less extent, maize itself, rice meal, and linseed cake. Fish meals derived from herring, mackerel, and other "non-white" fish impart a taint to the flesh. The best finishing materials are barley, potatoes, and beans.

Food consumption is ordinarily reckoned in terms of dry meal, 4 lb. of cooked potatoes, or about 5 to 6 lb. of fodder beet, or 8 lb. of swedes being reckoned as 1 lb. of meal equivalent. On this basis a pig of 50 lb. live weight will consume about 2½ lb. of meal (5 per cent. of its weight); one of 100 lb. about 4½ lb.; 150 lb., 5¼ lb.; 200 lb., 6¾ lb.; 250 lb., 7½ lb. (3 per cent. of the body weight). A pound of meal per month of age is a useful approximation. A common practice in production for Wiltshire bacon, at 200 to 230 lb. live weight, is to feed to appetite until consumption reaches 6 lb. per day, and thereafter to restrict the ration to this amount.

GENERAL MANAGEMENT

Pregnant sows should have ample opportunity for exercise, preferably in the open air and, in summer, on pasture. Many unsatisfactory litters, and many casualties among the young,

result from sows getting fat and lazy. In summer a rough but rain-proof shelter, with access to pasturage, can provide for a group of up to twenty. The same shed, with perhaps some additional provision against wind or driving rain, can be used in winter if the land is reasonably dry: otherwise a partially open yard is preferable.

Sows that finish lactation in a seriously reduced condition should have a short period of good feeding before they join the group, otherwise they may be bullied and prevented from getting their full share of food. The requirements of a pregnant sow, for maintenance and the rebuilding of body reserves, are met by about 6 lb. of meal equivalent. Good ordinary pasturage, or an abundant supply of good greenstuff or roots, will meet about half of these requirements, so that the actual allowance of concentrates may be about 3 lb. per day. Indeed, on very good clovery pasture satisfactory condition may be restored with 2 lb. of concentrate or, occasionally, less. For sows on pasture, feed-nuts are more convenient and less wasteful than dry meal or slop; these will be fully consumed if scattered thinly over the ground, and all the animals will have the opportunity of getting fair shares. On good clovery pasture or on lucerne a purely carbohydrate food will suffice, and soaked maize may be substituted for compound nuts. In winter the supplementary foods may be largely potatoes or fodder beet, in which case meal or nuts with a rather high protein-content should be used. If sows are kept indoors during pregnancy, with only limited amounts of greenstuff, it may be well to incorporate a trace of iron salts in their food, with the object of ensuring that their young will be born with good reserves of iron and will thus be unlikely to develop anæmia. Five to 10 gm. (say ¼ oz.) per head per day is sufficient.

Sows will ordinarily have been served before they join the group but, of course, may return to service; the group should therefore be looked over daily for signs of œstrus.

Each female, some ten or fourteen days before she is due to pig, should be moved to her farrowing quarters in order that she may be appropriately fed and have time to become accustomed to her surroundings. The udder should be washed with soap and water to get rid of any worm eggs that may be present on the skin. Her ration should be about 7 lb. of meal equivalent, mostly in concentrate form, rather laxative, and moderately rich in protein. Weatings (middlings or sharps), with the addition of perhaps

5 per cent. of fish meal and 5 per cent. of linseed meal, is a popular diet. An alternative is an ordinary sow-and-weaner mixture, with the addition of perhaps 20 per cent. of bran. Only a small amount of green food should be given. The pen should be kept clean and well littered with short straw, and the animal should be occasionally handled and petted.

Milk ordinarily appears in the teats about a day before the onset of birth pains, and, soon after, the sow will be seen to gather litter with her mouth and make a nest. Any long straw should now be removed and replaced with clean cavings or short straw; baby pigs are liable to become entangled in long litter and may fail to reach the teats, or be overlaid.

Nobody except the regular attendant should be present at farrowing, and there should be no interference with nature except in the very rare cases where help is clearly needed. In many cases, once parturition has begun and is seen to be proceeding normally, the sow can be left for intervals of an hour or so.

The chief danger is from an excited or nervous sow savaging or even eating her young or treading or lying on them, the risk being greatest with the first litter. If trouble is feared, the piglets, as they are born, may be removed to a warm box or barrel and kept covered up until farrowing has been completed and the dam has settled down. Sows that have once killed a litter should not be bred from again. The piglings' mouths should be examined and, if the incisors are very prominent or if the sow is evidently suffering pain during suckling, the teeth should be nipped off with pliers. It is an advantage to leave a light over the farrowing pen for a few nights.

During the first two days after farrowing the sow will take little food and should be offered only a thin slop of middlings or—if she is in very weak condition—some warm milk. Her demands will remain small for a further few days and will generally be met by a daily ration of 6 or 7 lb. meal, fed as a slop, and divided into two feeds. Many breeders withdraw green food entirely during the first week lest the sow's milk cause some digestive disturbance in her young. By the end of the first week the flow of milk will have greatly increased, and it ordinarily continues to rise during the succeeding fortnight. The ration must therefore be raised to 10, 12, or even, in the case of large sows with large litters, 14 lb. of meal per day (in three feeds) with a small allowance of greenstuff. A rough rule is some 4 lb. for the sow

and 1 lb. for each piglet, but few sows will consume more than 14 lb. The concentrate should be well balanced (see p. 759).

During the second and third week the attendant should watch for symptoms of anæmia since, even if a sod is placed in the sty daily, it may be neglected. If the skin and, especially, the ears develop a yellowish instead of the natural pinkish tinge, and if there is any tendency to scour, iron salts should be administered daily until the piglets are seen to be eating or nosing at the sod (see p. 758). The easiest means of prevention is to let the piglets out to grass for an hour or two daily.

To ensure continuing rapid growth after the sow's milk yield begins to drop, as it commonly does during the fourth week from farrowing, the piglets should be induced to eat as soon as may be. They must be encouraged with palatable and nutritious food which, since it must be constantly accessible to them, must be out of reach of the sow. Wet mash, though palatable when fresh, quickly turns sour, and dry meal is apt to be wasted. Thus small nuts or pellets are the best form. Some pigmen, if interest does not develop, sprinkle the food with milk. Appetite should develop fast and, by weaning time, consumption should have reached fully 1 lb. per day.

Males not required for breeding should be castrated about the fourth or fifth week of age; if the operation is delayed until near weaning time the animal suffers a double check. "Rigs" (cryptorchids) should be fed off before they are five months old since, after this time, their flesh develops the strong flavour of boar's meat. The minimum age for weaning is seven weeks, and eight or nine is normal. The weaners should be fed thrice daily and if, as is best, they are left in the sty where they have been born, food may continue to be left in the creep. It is preferable, at weaning time, to remove the sow, rather than the piglings, from the farrowing sty.

Regarding the rate of growth, piglings weighing 2 to 3 lb. at birth should reach an average of at least 30 lb. at weaning—unless, indeed, the litter is very numerous, when the two or three smallest, having been on the rearmost teats, may bring the figure down. In Denmark and New Zealand 30 lb. is considered to be a poor achievement; indeed, some New Zealand authorities mention 40 lb. as attainable in practice, but the assumption is that separated milk is available in unlimited amount. A 35-lb. average is, however, attainable without milk given well selected

stock and good management. Separated milk has an even greater effect upon growth rate than can be explained by the amount and high quality of its protein and its high digestibility. An allowance of even half a pint per day produces a marked response.

After weaning the growth rate, starting at about $\frac{3}{4}$ lb. per day, progressively rises to about $1\frac{1}{2}$ lb. per day at six to seven months (200 lb. live weight). For a further month or two the rate of gain remains about constant and thereafter declines. Breeding gilts, which should be kept in growing condition but not fattened, will ordinarily make rather less than three-fourths of the weight increases of bacon pigs. A table of weights-for-age is given in Appendix V.

The rate of live-weight gain is less important than the economy of gain (food consumption per pound live-weight increase). Up to a point, however, the two go together; assuming that the maintenance requirement is constant in relation to body weight, and that surplus nutrients are devoted to growth without fattening, a fast growth rate will be associated with a low total food consumption per pound of live-weight gain. On the other hand, the formation of body fat requires much more food energy than the growth of bone, muscle, and vital organs. It will be obvious that over-fattening is doubly undesirable for, on the one hand, the food cost per pound of carcass will be enhanced, while the carcass will be valued at a lower price.

Different authors have expressed rather widely different views about the size of carcass that can be produced at the lowest cost per pound. The cost of the weaner, per pound of carcass weight, will obviously be high, since the cost of maintaining a sow for six months, as well as depreciation, must be divided over the litter. In the early stages after weaning the economy of gain is very high, and it progressively falls with age. On the other hand, older pigs can consume increasing amounts of relatively cheap food—waste potatoes, fodder beet, swill, etc. The overall result is that there will often be little difference in costs, per pound of carcass weight, within a range of 200 to 250 lb. live weight. Porkers of half this size are substantially more expensive to produce, per unit of carcass weight; one calculation makes the difference about 25 per cent.

With regard to the level of feeding there is general agreement that animals being reared for slaughter should be fed concentrates

to appetite—as much as they will clean up in about twenty minutes—until the age of nearly six months (by which time the consumption will be about 6 lb. per head per day), but that, thereafter, the allowance should be restricted to about 6 or $6\frac{1}{2}$ lb. daily. In the early stages full consumption should be encouraged either by providing three meals daily or, alternatively, by feeding twice daily and allowing access to a self-feeder. Feeding to appetite after the age of six months will, in most cases, result in an overfat carcass and a poor ratio between food consumption and live-weight gain. The exception may be made in the case of animals of the largest and latest-maturing types, which may profitably be fed to appetite throughout. The poorest carcasses, and the poorest returns for food consumed, result from under-feeding in the early stages (which restricts growth and the development of muscle) followed by over-feeding in the latter part of the animal's life, which leads to a large accumulation of expensive and unwanted fat.

In the rearing of breeding gilts the objective is to secure nearly full growth with very little fattening. This can best be achieved by reducing the allowance of concentrates to about three-fourths of the amount that would be eaten by, or would be appropriate to, a slaughter pig of the same age, and by allowing the animals to satisfy their hunger by grazing, or by consuming such bulky foods as kale, clover, roots, etc., to appetite.

The control of diseases and parasites is of prime importance. The most disastrous of the commoner infections is Swine Fever, and unless there is a high degree of isolation from possible sources of infection, vaccination should be carried out as a routine. The incidence of Swine Erysipelas varies much as between districts, and veterinary advice should be sought on the desirability of immunization. Outbreaks of coughing may be due to virus pneumonia, and veterinary advice should be sought.

Periodic worming is desirable even if there is no obvious sign of infestation, since it is much cheaper to prevent a build-up than to deal with one after it has occurred. The best of known medicaments is sodium fluoride, its only disadvantage being that the dosage must be accurately adjusted to the size of the animals, varying from $\frac{1}{4}$ oz. at weaning time to $\frac{3}{8}$ oz. at maturity.

A watch should be kept for the appearance of lice, which generally first show about the ears. A soapy emulsion of derris, applied to the skin with a brush, will kill the living specimens

but not the nits, so that treatment should be carried out twice with an interval of a fortnight.

The droppings should be watched. If the animals are constipated a mild laxative should be administered by way of the food, and modification of the ration—*e.g.* the addition of some bran—may be considered. Scouring may be a symptom of serious disease; on the other hand, it is often due to particular foods—*e.g.* unripe fodder beet. If the trouble appears to be caused by some irritant in the food, castor oil may be administered, and the animal put, for a few days, on an invalid diet of flaked maize and water.

Outbreaks of fighting are liable to occur, sometimes without obvious cause, but most often when lots of well-grown animals are reassorted. It may happen that one particular animal is set upon by all its pen-mates and be seriously injured, or even killed. In general, the introduction of strangers should be avoided; it is, indeed, rarely practicable to keep each litter separate from start to finish, and, in fact, weanlings rarely give much trouble. At more advanced age resentment of strangers is much stronger. Sometimes the trouble starts when the pigs outgrow their trough-room, and needs in this respect should be borne in mind when the pens are being filled. In large herds it is possible to work to a plan that both economizes space and conduces to peace in the herd. This is to run the weaners, in batches of thirty or forty, in yards and, when they are perhaps four months old, to divide the batch into evenly sized groups of eight or ten for transfer to the fattening pens.

CHAPTER VIII

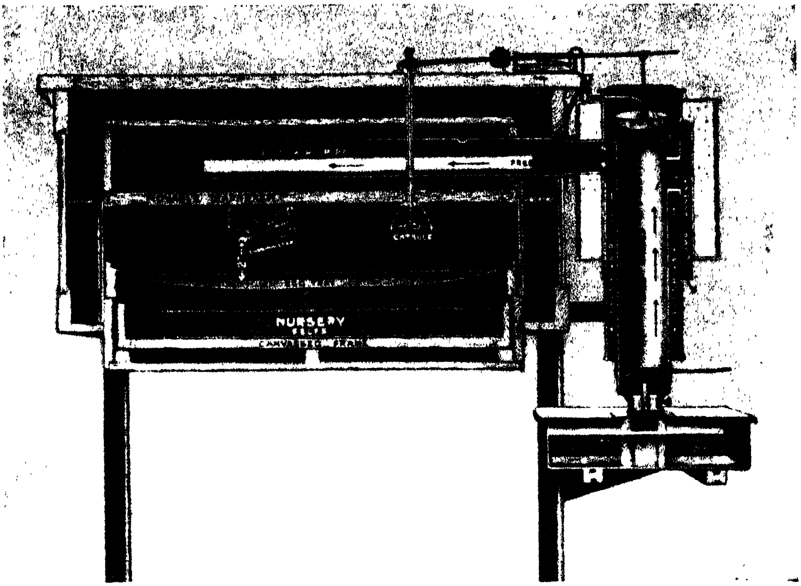
FARM POULTRY

THE domestic fowl appears to be descended from *Gallus bankiva*, a species of wild fowl indigenous to that region of Asia comprising Burma, parts of India, Sumatra, etc. By the beginning of the Christian era the birds had probably reached Europe, their domestication and spread having been due partly to their value as food producers but also very largely because of the sport provided by cock-fighting. Fowls have proved themselves to be particularly adaptable; they have been moulded into a large number of breeds and varieties, each possessing special characteristics.

In order at the outset to get a broad view of the management of poultry, it may be helpful to compare the life of the wild bird under natural conditions with that of modern fowls kept for commercial purposes. The wild Jungle Fowl breeds only once a year, lays a clutch of eggs, broods and incubates the eggs, and looks after the young for as long as is necessary. The young reach sexual maturity at a year old. Moulting takes place once a year or oftener.

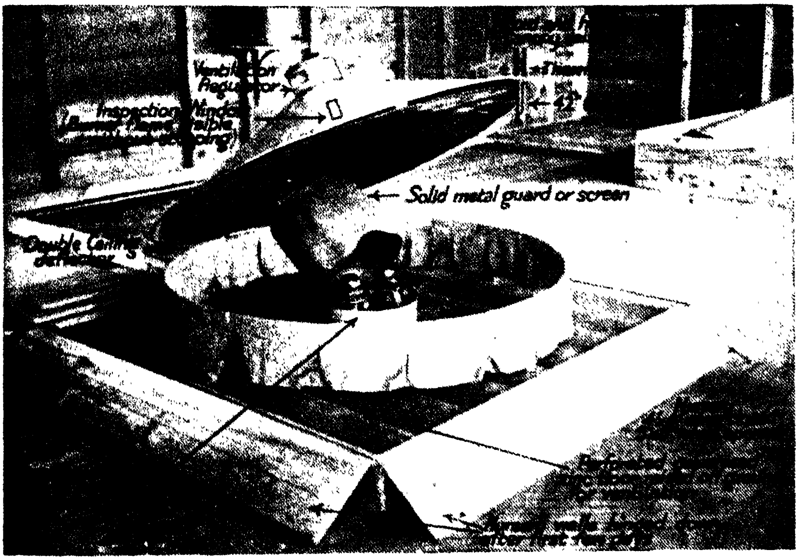
Breeds used in poultry farming have been selected so that the short natural laying period has been extended to a period of perhaps ten months, and the natural clutch of a dozen or more eggs has been increased in many cases to over two hundred. To get this high production, birds have been so bred that they seldom go broody and do not pause in laying during winter. In order to reduce the costs of maintaining unproductive birds, modern fowls have been developed to reach sexual maturity and commence laying when about six months old. In commercial practice the time of hatching is adjusted so that the young birds lay a large proportion of their eggs during winter, which, because it is the " unnatural " season, is the time of relative scarcity and high prices. But fowls that are producing eggs in the winter season require to be protected by suitable housing and provided with ample and correct food. During winter the production of eggs may be stimulated by providing artificial light.

Although the laying powers of fowls have been developed to an extraordinary degree, production does not continue indefinitely,



Gloucester Incubator Co.

A. Section of Gloucester Incubator



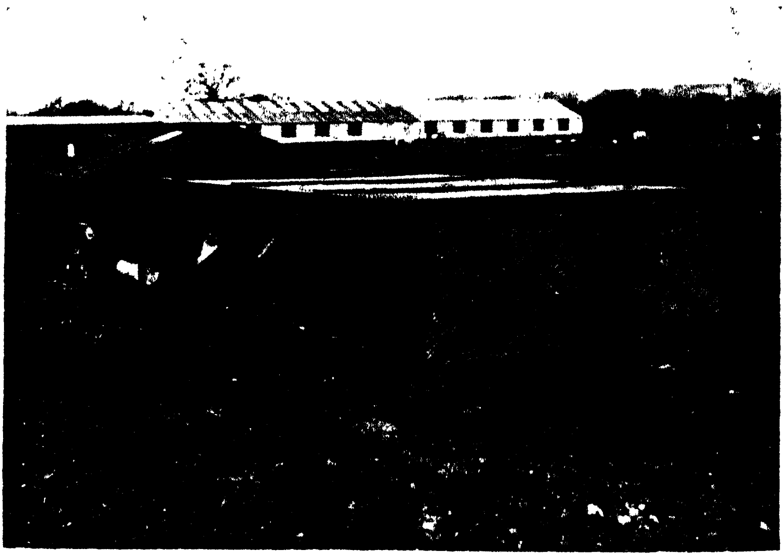
W. H. Colt, Ltd.

B. "Sondix" Brooder

PLATE LXVIII

Boulton & Paul

A. Movable General-Purpose Poultry House



Boulton & Paul

B. Folding Unit

and even where broodiness has been eliminated the time comes when the birds stop laying and go into a moult. There are, however, indications that it might be possible to breed non-moulting strains. In order to get supplies of eggs at all seasons, chickens are normally reared over a three- or four-month period so that the flock as a whole will have fowls commencing and finishing laying at different times. In addition, an endeavour is made to have the young birds start laying before the older ones begin to moult. In spite of much being done to equalize the distribution of egg-production throughout the year, most eggs are laid during the "natural" laying season in spring, particularly in the less intensively managed flocks. In the past, production in March-April-May has been sufficiently high for eggs to sell in a free market at about half the price that obtains in October-November-December; but this relationship has been changed by the increase in the proportion of flocks kept under the battery and other indoor systems.

Egg-production is the main business of most poultry farmers, and in many cases the birds sold for table purposes are surplus stock, of all kinds and qualities, which have had no special preparation. In many districts the price of table birds is too low to justify the special feeding and finishing required for the production of the highest quality carcasses. It may at times pay to finish fowls of the dual-purpose and table breeds, but the light "egg-laying" birds are difficult to sell, and where there is no market for *petit poussins* it may be best to destroy cockerels of Leghorn and other light breeds as soon as their sex can be determined.

Before going on to the details of poultry husbandry it is worth alluding in a very general way to the management of a commercial flock. In a flock of dual-purpose fowls mating usually begins in December; the first hatchings take place in January and other hatchings follow until April. The chickens are first kept in brooders with artificial heat and then in cold brooders. When the sexes can be recognized the male birds are removed to be reared for the table or otherwise disposed of. The female chicks are brought to maturity so that they will begin to lay when six to seven months old. The pullets provide winter eggs and should continue to lay until they go into moult between the following August and November, when their place is taken by that year's pullets. Considerable losses, averaging perhaps 30 per cent.,

occur during the first twelve months of production. Once moulting starts, the hens have usually to be kept until December or January before they lay again, and for this reason, and because a hen in her second year gives but 70 or 80 per cent. of her first year's production, only the best of the birds are kept for a second season. The culls are disposed of as soon as, or even before, they stop their first period of laying. The breeding pens are made up of birds commencing their second laying year, and when this second period of production is completed the two-year-old birds are sold. Only very valuable breedingstock is kept beyond thesecond season.

Breeds.—The breeds of poultry are so numerous that they cannot be considered in detail in this work. Broadly, however, they may be grouped into those that have been developed primarily for egg-production, those that have been selected for table, and the dual-purpose varieties that are suitable for both purposes.

The egg-laying breeds, as the name implies, are all heavy layers. In them the tendency to go broody has been largely eliminated. They have light bodies and are consequently rather inferior meat producers; indeed, surplus male birds are usually not worth feeding for table purposes. Being light, lean, and often not very heavily feathered, they are not as a rule hardy enough for the most exposed situations. On the other hand, they are very active and keep themselves fit in the relatively close confinement of intensive houses and backyard runs. They are rather too nervous, however, for keeping in individual cages, and they become very excited when they are moved in folding units. They lay eggs of white colour. Of the breeds in this group the most important is the White Leghorn—an Italian variety which was imported to this country by way of America. A typical cock weighs about 6 lb. and a hen 4½ lb. Other representatives of this group are the Brown and Black Leghorns, the Ancona, the Andalusian, and the Minorca.

The table breeds show considerable variation in size, egg-laying capacity, colour of flesh, colour of egg, and so on. The quality they have in common is heavy fleshing. Some are coarse-boned and slow to mature. The most popular is the Light Sussex, which is of English origin, and combines fine meat quality with very good egg-production. A male bird weighs about 9 lb. and a hen 7 lb. Other table breeds are the Faverolle, the Dorking, and the Indian Game.

The best of the dual-purpose breeds have good carcasses and also produce eggs in such numbers as to rival the specialized egg-laying varieties. They are particularly hardy and good winter layers, which may be because they carry more fat and feather. They have the disadvantage of being prone to broodiness, and unless they are watched and treated their egg yield may suffer on this account. They do not all have the activity that is necessary in birds that have to be kept in confinement, where inactive fowls tend to become fat and excessively broody. They nearly all lay brown or tinted eggs. Rhode Island Reds and Light Sussex are the most popular of the dual-purpose breeds; they are approximately of the same size, the males weighing about 8½ lb. and the hens 6½ lb. Other dual-purpose breeds are Barnevelders, Orpingtons, White Wyandottes, and Plymouth Rocks.

Selection and Breeding.—Under intensive and semi-intensive systems of management, farmers should aim at an average of considerably more than 150 eggs per bird in its first laying year. It is only under conditions where fowls are kept purely as scavengers, at the least possible cost, that low egg-production can be profitable. Not only is it essential to breed only from good strains but it is also necessary to rid the commercial flock of birds that are unproductive. In every batch of pullets that is reared there will be some that are quite incapable of giving a sufficient return to pay for their keep, and these must be culled and sold for what they will fetch before they occasion further loss. Trap nests can be used to obtain a measure of production, but a very good idea of a bird's laying capacity can be had from its appearance and behaviour. The best hens are those that mature early and lay well in the October-November-December season; indeed it is a good plan to mark pullets that are laying well at this time so that when they are mature they may be retained for breeding. Good layers show an active nervous temperament and search long and far for food, while less desirable birds tend to be sluggish. In good fowls the head tends to be broad yet refined and the eye is bright and prominent; in poorer specimens the head may be too fine or too coarse and "beefy," and the eye dull and sunken. The comb and wattles become large, red, hot, and smooth in birds that are laying, but bluish, shrunken, scurfy, and cold when no eggs are being produced. The bodies of good fowls show roominess and a large digestive capacity. Flexible pelvic bones placed wide apart, and a large moist vent, are other

indications that the bird is laying. Fowls which ordinarily possess yellow pigment in the beak, legs, and other parts lose this colour when they are producing eggs continuously; the colour of the beak may be lost after five or more weeks' lay, and that of the legs after fifteen weeks or more. The best birds moult late in autumn—that is, in October and November; they lay right up to the beginning of their moult and then moult rapidly. The September moulters should be culled; but birds may be retained if they have completed their moult by the 1st of September and are again about to lay. When pullets moult in their first year it is generally due to faulty management (see pp. 784-787).

The inheritance of high egg-production is by no means simple: it is probable that separate hereditary factors for early sexual maturity, broodiness, intensity of production, tendency for a winter pause in laying, and persistency in laying, all contribute to the total result. Factors for vigour and digestive capacity add further complications. It is doubtful if mass selection can really lead to much further improvement; indeed it has been stated that analyses of records show no relationship between the production of daughters and that of their dams or their sire's dams. At best the correlation between a dam's production and a male bird's worth seems to be low. It therefore follows that the only effective way of increasing the egg-production of a flock is to use birds that have been selected by means of a progeny test (see p. 536). By contrast with other types of live stock, progeny testing can be applied to females as well as to males. An individual hen can produce enough daughters in a single year to provide good evidence of her genetic make-up. Of course birds must be selected for other things as well as egg yield: the shape and size of the eggs are important matters; the fowls must also conform to breed standards. In a few cases good producers are unsatisfactory breeders because their eggs are of low hatchability.

In the practical mating of the birds the males must be put into the pens some time before the eggs are taken for hatching. Actually the eggs should be fully fertile five days after the first mating. With dual-purpose breeds a cock is run with 8 to 12 hens, and with light breeds the ratio can be 1 to 10 or 15, but rather more hens may be given where there are several males running in the flock. The use of cockerels produces the greatest proportion of fertile eggs, but a bird that has proved his worth in a progeny test is, of course, kept as long as he is useful. Hens in their second

laying season lay larger eggs than pullets, and are generally preferred for breeding since they have proved their ability to survive. Pullets are sometimes used as breeders, but when this is done they should be hatched early, and after laying for a time it is better that they should moult and rest for a while before the start of the breeding season. Fertile eggs will continue to be laid for five days after the removal of the cock, and by the tenth day fertility will have fallen to about 50 per cent. One reason for low fertility in practice is that some hens may be neglected by the male bird.

Pen mating is very common—that is, each male bird and his group of hens are penned separately. Mass or flock mating is sometimes practised; this consists of running all the male birds with the entire flock of hens. The obvious disadvantage of mass mating is that it is quite impossible to keep any record of pedigrees, but on the other hand, eggs from such mating show high fertility. A technique for artificial insemination has been developed and this enables a very large number of females to be fertilized by one male.

With special breeding stock very elaborate records have to be kept. Egg-production is recorded by means of trap nesting, the individual birds being distinguished by numbered leg-bands. Hatching eggs may be marked with their pedigree and incubated in special bags or cages to keep the chicks separate until they are numbered by leg- or wing-bands. In addition, coloured rings are slipped on the legs of the birds for special purposes. Where trap nesting is not practised the early layers among the pullets may be given a coloured band, so that they can be kept for breeding in the following year.

Sex-linkage in Breeding.—It has already been pointed out that male chickens of certain breeds are often worthless. With other breeds it may pay to rear for table purposes chickens that have already been kept long enough to render their sex apparent, yet if the sex could be distinguished at the outset it might be better to get rid of the cockerels than to feed them for meat. With the older pure breeds there is nothing to indicate the sexes until the secondary sexual characters begin to develop, but by crossing birds possessing certain characteristics it is possible to separate the sexes with almost absolute certainty at the time of hatching. Owing to sex-linkage, the sons of hens having the following characteristics resemble their dams when got by cocks of

the opposed type; conversely, the daughters resemble their sires :—

1. A ground colour of creamy silver as opposed to buff or golden brown. For example, Light Sussex, Silver Wyandotte, and Silver Hamburgh hens mated to Brown Leghorn, Buff Orpington, or Rhode Island Red cocks will produce silver males and gold-coloured females.
2. Barred plumage as opposed to unbarred. For example, Plymouth Rock, Scotch Grey, and Cuckoo Leghorn hens mated to Black Leghorn or Black Minorca cocks produce male chicks with a light head patch and black pullets.
3. Light-shanked as opposed to dark (slaty) shanked. For example, White Leghorn and White Wyandotte hens mated to a La Bresse cock give light-shanked male chicks and dark-shanked pullets. These characters, however, are not so easily distinguishable as those in cases 1 and 2.
4. Slow-feathering as opposed to rapid-feathering. For example, hens of the heavy breeds, which tend to be slow-feathering, as opposed to a rapid-feathering breed such as a Leghorn. Thus slow-feathering male chicks can be got by using a Rhode Island Red hen and a Leghorn cock. The disadvantage here is that the unwanted birds may have to be kept for some days and even then it may require experience to distinguish the sexes.

It may be of interest to consider the mechanism whereby this sex-linkage takes place (see also p. 527). The cock has two sex chromosomes but the hen has only one; the result is that while every male gamete (sperm) has a sex chromosome, only half the female gametes (ova) are so equipped. Now if the character for colour is carried in the sex-chromosomes, half the ova will carry no colour factor; if one such ovum should fuse with a male cell the offspring can only inherit the colour of the male, and as it has only one sex chromosome it must be female. If the colour carried in those ova which do have sex chromosomes should be dominant to that carried by the male cells, the offspring will have the colour of the mother; and because they get a sex chromosome from each parent they will be males.

Sex-linked breeding can only be carried out where the dominant factor is possessed by the female. For example, if a

pure barred cock is crossed with a black hen the chickens of both sexes will be barred. With certain combinations of colour factors, however, even pure-bred chicks are distinguishable at birth. New breeds such as the Cambar and Legbar have this characteristic. The Legbar is simply a Brown Leghorn to which the barred character (alternating light and dark marks across the feathers) has been added. Legbar pullets can be produced cheaply and easily from any Brown Leghorn stock by mating a pure Legbar male with ordinary Brown Leghorn females. As the barred character is sex-linked it is passed from the father to his daughters. The sons of this cross are also barred, but as they contain their mother's unbarred character they are impure and unfit for breeding; they are indistinguishable from females at hatching and have to be kept until their combs and tails disclose their sex. When pure Legbars are mated together the sex of the offspring is distinguished by the shade and pattern of the chicken down. Unfortunately the progeny of some Brown Leghorn stocks show differences that are not very sharp. Many people can be trained to distinguish the sexes of young chicks by examination of the vent, but a considerable amount of practice is necessary before anything approaching certainty can be reached. Chick-sexing instruments, which simplify the process, have recently been developed.

While first-cross hens may often show vigour and productiveness superior to those of their parents, the great disadvantage of sex-linked or other crossing is that the birds cannot be used for breeding because second crosses are of inferior quality.

Incubation.—Hatching chickens in the natural way by means of broody hens is too laborious for modern conditions, and about nine birds out of every ten are now hatched by artificial means. Incubators vary from a 50-egg size to mammoth machines which can hold thousands of eggs at a time. While they differ in capacity and in details of construction, they are all insulated containers equipped with one or more drawers to hold the eggs and provided with a heating device and some means of securing a constant temperature. The popular small incubator of, say, 150-egg size (see Plate LXVII, *A*) has a paraffin lamp and a thermostatically controlled heat-regulating damper; it is constructed so that the egg temperature is maintained by a current of hot air; it may or may not have a quick-turning device fitted to the egg tray. Mammoth incubators are heated by oil, coal, or electricity, and a fan is employed to ensure thorough circulation

of the heated air and to maintain a uniform temperature; their numerous drawers can be tilted so as to turn the eggs. Full particulars of the construction, care, and maintenance of incubators can be had from makers' catalogues and handbooks.

Incubators should be housed in a soundly constructed and properly insulated building where there are no draughts and where a fairly uniform temperature can be maintained. A room or a cellar in a dwelling-house may accommodate the incubators for a small farm flock. A hygrometer is a useful fitting in the incubator room, for it will enable measures to be taken to adjust the humidity.

In deciding on the incubator capacity for a particular size of flock there is much to be said for being able to hatch all the required chickens in two batches, and at most it should be possible to do the hatching in three. For hatching on a large scale it is better to use a mammoth machine than a number of small ones.

Of every 100 hens in a farm flock, roughly 75 should be pullets and the remainder yearling birds that have been kept for breeding. In order to obtain 75 selected pullets, about 85 will have to be raised, so as to allow for the culling of 10, and in order to raise 85 it will be necessary, because of some mortality, to hatch 100. As half of the chickens will be males, the hatch will have to be one of 200 birds. But of the eggs put in the incubator it is reasonable to expect that only 60 or 70 per cent. will hatch, so that the total number of eggs required will be 300, or 4 eggs for every pullet that is wanted. Obviously the incubation could be performed by setting a 150-egg incubator twice.

It has already been indicated that the first hatchings of heavy breeds will take place in January or February; light birds such as Leghorns, which take about a month less to mature, can be hatched among the last batches. Early hatched chickens do better than late, and in addition, table cockerels from early lots can be marketed to advantage before supplies become too heavy. Hatching for egg-production should be completed by the middle of April. Birds for table purposes may be hatched in autumn so that they can be marketed during the high-price period in early spring. Summer hatching may be practised with a view to the Christmas market, and where a contract can be made for regular weekly deliveries of table birds, hatching may continue throughout the year.

The eggs from the breeding pens hatch best when they are not more than five days old; there is a loss of about 20 per cent. in

eggs that have been kept a fortnight, and those over three weeks old may be considered useless for hatching. If eggs have to be collected over a considerable period they should be stored at about 50° F.; and in no case should they be kept at a high temperature, which would reduce the vitality of the germs. The eggs should be free from cracks and they must not be washed, but may be dry-cleaned with wire wool.

The incubator is run for two days in order to get it regulated before the eggs are placed in the trays. The temperature is of very great importance and it must be watched with great care. When the thermometer bulb is about 1 in. above the eggs the temperature should usually be 102°, 103°, and 104° F. in the first, second, and third weeks respectively; but it is generally best to adhere closely to the makers' instructions regarding this point.

It is necessary to turn the eggs frequently in order to prevent the embryos sticking to the shell membrane. When the turning has to be done by hand it should be performed twice daily from the beginning up to and including the eighteenth day. But eggs benefit from frequent turning, and with machines fitted with quick-turning drawers it is worth carrying out the operation four times a day. It used to be customary to cool the eggs periodically, but investigations have shown that cooling in itself does no good. In incubators where the ventilation is poor, however, it may help the hatch if the eggs are aired for five, ten, and fifteen minutes daily in the first, second, and third weeks respectively. Cooling is quite unnecessary in mammoth incubators where the air is circulated mechanically.

In small incubators eggs are tested twice during the incubation period to reveal infertiles and dead embryos, the examination being carried out by holding the eggs against the light of a testing lamp. The first test takes place from the fifth to the eighth day, and all the infertile eggs and those with dead germs are removed; a second test between the fourteenth and eighteenth day permits of the removal of eggs whose embryos have died since the first test. Infertile eggs are clear when lamped. In the first test the fertiles show the living embryos as small dark spots radiating blood-vessels, but in dead embryos the blood settles away from the germs and about the edges of the yolk. In the second test the living embryos fill the eggs well but the dead ones show only partial development. In mammoth machines eggs are tested once only, generally on the eighteenth day.

During incubation relative humidity should be between 55 and 65 per cent.; that is to say, the air should be neither too dry nor too wet, for both extremes injure the hatch. Ventilation is very important, and especially towards the end of incubation when respiration is active within the egg. If the percentage of CO_2 should rise too high the hatch will be very seriously diminished.

Hatching takes place after twenty-one days' incubation. Temperature and humidity should both be maintained during the last stage; and since inspection merely reduces both, and so injures the hatch, the incubator should not be opened after the eighteenth day until the hatch is completed. Chickens should be kept in the nursery drawer of the incubator for not less than twenty-four to thirty-six hours before being taken to a brooder; during this time they require no food.

Brooding and Rearing.—As soon as the chickens are hatched they are susceptible to infectious diseases and parasites, and successful rearing is therefore as much a matter of sanitation as of nutrition. It will help to keep an outbreak of disease within reasonable bounds if the batches of chicks are not too large, and 350 per lot should not be exceeded. Most important of all, as diseases and worms are almost certain to be present to some extent in old birds, chickens should never mix with adult fowls nor have access to soiled ground. It follows, therefore, that brooding should be done either on clean ground or in a system of housing which protects the birds from all risks of infection. Experience suggests that outdoor rearing, while it results in some degree of parasitic infection, produces birds of greater stamina and disease-resisting powers than those that are reared on the intensive systems. Day-old chicks or hatching eggs should be bought only from flocks that are free from pullorum disease. Freedom from this can be obtained by blood-testing the breeding stock and by rejecting the reactors.

Brooder houses should be well lighted, well ventilated yet draught proof, and easy to work in and keep clean. They may be small and portable or large and centralized: in the latter case they are divided into brooding compartments and may have a food store and a central-heating plant. The floor space in brooders should be 50 sq. ft. per 100 chickens, and there should be 7 sq. in. of hover space per chick. When only soiled ground is available the brooders may have sun-porches which enable the birds to get

air and direct sunlight; in order to reduce the risk of infection the porches may have wire-mesh floors placed 1 ft. or more above ground.

The essentials of a brooder are a heating device, a cowl to intercept and hold the heat over the brood, and a control to maintain a set temperature: the actual arrangement under which the birds seek warmth and comfort is usually a hover (see Plate LXVII, *B*); but a brooder may be simply a ventilated wooden chamber with a heating lamp. The smallest sizes, which are portable, are generally heated with a paraffin lamp and made for batches of about 100 chicks: they can be used one to each brooder house or one to each brooder compartment. Electricity is very suitable for heating brooders in fixed houses if it can be got at a reasonable price, and it has the advantage that the temperature can be very exactly controlled by an electric thermostat; it saves much trouble and cleaning. Anthracite stove brooders are very good for batches of 200 chicks and upwards, one being used for each house or division. A centralized hot-water system is useful for large brooder houses, the water being taken to a radiator in each brooder compartment, or the hot-water pipes buried in the concrete floor so that the whole or part of the floor itself is heated. Battery brooders consist of a series of wire-floored compartments placed one above the other with a droppings tray under each. The temperature in each compartment is adjusted according to the age of the chicks. The birds in any one compartment are forced to remain in the same temperature, which has an enervating effect; and although growth may be rapid, feathering is poor and stamina somewhat lacking. Tier or table-type brooders are modified battery brooders, in which there is a cool as well as a heated section in each compartment, so that the chickens can get away from the heat. This arrangement overcomes, to some extent, the limitations of the battery brooder, and tier brooders are quite suitable for rearing commercial stock for the first few weeks. For rearing potential breeding stock less intensive methods are to be preferred.

Brooders should be got going a couple of days before the hatch is expected, so that the temperatures can be adjusted and the surroundings dried and warmed. The chicks should be brought in a container which will prevent their being chilled. A ring of netting is first placed round the brooder to keep the birds from wandering too far from the heat; it is widened from time to time

until it is taken away after about four days. The temperature under the hover should be about 90° to 95° F. to begin with, and it should be reduced gradually to 70° or 75° F. by the end of the fourth week, after which the heat is kept constant until it is needed only at nights; by the sixth or ninth week, depending on the season, it may be discontinued altogether. Actually, however, the temperature is adjusted according to the behaviour of the chicks: if too cold the birds crowd, while if they are too hot they gasp and show distress, or move away from the heat. In very cold weather heat must be supplied until there is no more risk of crowding. To make sure that ventilation is adequate, the curtain of the hover should not quite reach the floor, and the hover is gradually raised as the birds grow and harden off. Roosts are introduced at about four weeks so as to encourage the birds to perch, and the sexes are separated at six or eight weeks.

The unwanted cockerels are transferred to pens for fattening. The pullets should be put on clean ground—in slatted-floor arks, folds, or colony houses—and there be retained without further change until they are ready for the laying house. The perching requirement in the house will be 6 in. a pullet by the time the birds are well grown. After a change over, the fowls are kept housed until they are used to their surroundings, or a net can be run round the house to keep the birds from straying too far. The stock cockerels, like the pullets, should be raised in clean, healthy surroundings.

Housing.—Apart from the incubator room and storage for utensils, food, tools, etc., houses are required for (*a*) Brooding, (*b*) Rearing, (*c*) Laying, and (*d*) Breeding. The actual selection of houses must depend on the size of the flock, the ground available, the system of management, and so on. Before dealing with the systems of poultry keeping it may be helpful briefly to review the types of house[1] that can be employed for the different flock groups.

Brooder Houses.—(*a*) Portable brooders or "nurseries" made to take about 100 chicks: they have a well-insulated chamber that is heated by a lamp, and a cooler chamber where the birds normally exercise and feed; they should be placed on clean grass, so that the chickens may be allowed out during good weather and when they are older. (*b*) General-purpose houses,

[1] For the details of house construction, see *The Housing of Poultry*, published by the Ministry of Agriculture.

each fitted with a portable hover or indoor rearer, and capable of taking from 150 to 250 chicks. They can at a later stage be fitted with perches and so serve for rearing; indeed they may be used for pullets right through their laying period (see Plate LXVIII, *A*). (*c*) Multiple-unit brooder houses, provided with a passage-way and divided into compartments, each of which is fitted with a hover. (*d*) Battery-brooder houses. These have to be specially insulated and ventilated to deal with the large-capacity brooders.

Rearing Houses.—(*a*) General-purpose houses can, as stated above, be used for rearing as well as brooding. (*b*) Slatted-floor arks or folds, which are easily moved, may be used when the chicks are ready to leave the brooder. Where free range is not given, each ark may have a netted run. (*c*) Range shelters may be constructed very cheaply and serve for growing birds. They are generally made with a sound roof over the perches, and the wall frames are merely covered with netting.

Laying Houses.—(*a*) General-purpose houses of the type used for brooding and rearing can, as already stated, be used for laying. When mounted on wheels or runners the smaller sizes can be moved, with the aid of a horse, from one part of the farm to another. These houses are designed for the semi-intensive system, are provided with netted runs, and are sited on grass. An alternative is the henyard system, under which the runs may be considerably reduced in size and kept littered with straw. In the former case the house can be used to confine the birds in bad weather, but if small enough to be conveniently portable it will only hold 12 to 20 hens. In the latter case a portable house with 40 sq. ft. of slatted floor will accommodate 40 to 50 laying birds, and this results in relatively cheap housing; but the hens cannot be confined. (*b*) Fixed laying houses to take 100 to 150 birds. Since the best yields are usually obtained from fowls running in small groups, houses of greater capacity should be divided into sections accommodating not more than 150 birds each. These houses are designed for the semi-intensive system of poultry husbandry and they are provided with netted runs. (*c*) Intensive houses where birds are confined all the time and which, for the sake of cheapness in construction, may be several stories high; they may have sun-porches. (*d*) Folding units with slatted floors and attached out-runs (see Plate LXVIII, *B*). These accommodate about 25 birds and are provided with some device whereby they can be moved by hand daily on to clean land. (*e*) Laying battery houses where each

individual hen is placed in a wire-fronted cage, the cages being arranged in several tiers one above the other.

Breeding Houses.—(*a*) The general-purpose colony house can be used for flock mating. (*b*) Houses to hold a male bird and his complement of hens may be set in separate enclosures. (*c*) Folding units can also be used as breeding pens.

Male birds can be reared in general-purpose houses, arks, or range shelters. The fattening cockerels may be kept in spare buildings about the farm and finished in fattening coops.

The houses have to be equipped with water fountains, mash hoppers, grit boxes, etc., of a size suitable for the age of the birds. Nests and broody-coops are, of course, needed in laying houses. The hoppers should be so constructed that the birds can neither scratch out nor foul the mash.

Systems of Poultry Keeping.—*The Free Range System* consists of running the fowls on unfenced ground. It is suitable for a general farm because, if houses are provided to accommodate about 50 birds per acre, and placed at least 80 yds. apart, the ordinary stocking of the land will suffer little interference and the birds will remain in their own colonies. Movable general-purpose houses are very suitable for this system, as they can be pulled on to other ground when the land is to be broken up for cropping, or they may be run on to the stubbles after harvest. Even when the houses are fixed, the light stocking ensures that the ground will not be seriously contaminated. As no fences are required, and as slatted-floor houses holding a laying bird per square foot of floor may be used, the cost of housing the flock is very small; moreover there is a further saving because the wide range provides the fowls with all their greenstuff and much insect and other animal food. On the other hand, the unprotected chickens and hens may suffer severe losses from birds and beasts of prey, and the wide spacing increases the labour of attending to the flock.

If general-purpose houses are employed they may be used in conjunction with portable hovers for brooding the chickens, and later on for rearing, laying, and flock mating. Quite often, however, the brooding arrangements are centralized and the free range is used only for rearing and laying.

The Folding System consists of keeping the fowls in small portable houses with attached wire-netting out-runs, the whole forming a "folding unit." The houses have slatted floors and are provided with all that is necessary in the way of nests and

food- and water-containers; they are usually made to hold two or three dozen hens. The units are moved daily on to fresh ground so that the birds, although relatively closely confined, remain healthy; the droppings are evenly spread and improve the herbage. As the run is completely netted in, there is little danger from vermin. This system is very suitable for a mixed farm and can be used on pasture that is carrying other stock. On the other hand, the method is being used fully to stock the land at the rate of about 400 birds per acre. The units are suitable for rearing birds and for layers, and they have even been used for breeders; they are unsuitable for brooding young chicks.

The Semi-intensive System is one in which a considerable degree of centralization is obtained by providing fixed houses and permanent runs. Wire netting is used to make the enclosures, and it is common to provide two or more out-runs for each house, so that while one is in use the other may be rested or even dug over and resown. The stocking should not exceed 300 hens per acre. The system is economical in labour and in the use of the ground but it requires extra capital for fencing, and the birds can hardly be expected to do so well on old runs as on fresh young pastures. The floors are littered with straw, chaff, or other suitable material, and provide scratching and exercising ground when the birds are confined during spells of very bad weather.

The henyard is a modification of the semi-intensive system. In place of the grass run the birds are given access to an uncovered but well-sheltered yard which is periodically littered with straw. The house should provide 2 sq. ft. per bird, and the yard about twice as much.

In this system brooding can generally be carried out most economically in a multiple-unit brooder house. The young birds may be reared in the ordinary houses and runs, but it is a great advantage to have clean ground on another part of the farm where they may be kept in slatted-floor arks or in range shelters. Small houses and runs are usually provided to accommodate the breeding fowls, and these permit of pen mating.

The Intensive System is one wherein the laying stock are kept entirely in confinement. The houses should be well insulated and ventilated. Ample light must be provided. Each bird is allowed about 3 to 4 sq. ft. of floor. Formerly the floor litter was removed periodically, but now it is commonly left to accumulate. If environmental conditions are satisfactory, composting

of the litter and droppings occurs, heat develops, and the litter remains dry and friable. Periodic additions of fresh litter are made; hence the method is described as the "built up" or "deep litter" system. It is labour saving and requires less capital to start, but demands a higher degree of skill in feeding and management than the battery system. In the battery system the birds are kept in individual cages arranged in tiers after the fashion of battery brooders. The whole arrangement is called a hen battery. Very little ground is required for this system and it is relatively labour saving, especially at week-ends. As individual egg records can be kept, culling is simplified; and battery culls command good prices as table birds, for their flesh is obviously more tender than that of birds allowed free range. On the other hand skilful feeding is necessary, as the birds have no opportunity of getting natural food and so correcting deficiencies in their rations. Birds kept intensively for commercial egg production are generally disposed of after one laying season.

During the short winter days egg production can be increased by using artificial light to lengthen the day to one of about fourteen hours. This extra light, functioning through the eye of the bird, stimulates the ovary to produce more eggs, and consequently the bird requires more food. The old theory that additional light increased egg production simply by allowing the bird more time to eat is no longer held. Once extended lighting has been introduced it must be continued, otherwise the birds will be thrown into a partial moult and cease laying. Artificial lighting, when started in late August, is particularly helpful in preventing pullets hatched late in the previous autumn or in January or February of the same year from going into a premature moult.

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Under the head of "Brooding" it has been pointed out that poultry rapidly contaminate the soil with worm ova, coccidia, and other disease organisms; hence heavy or continuous stocking will sooner or later result in many unthrifty birds and smaller returns. It is particularly important that young chickens and developing pullets should be protected from disease and kept off soil that has carried poultry within recent years. Coccidiosis has long been the worst of the diseases associated with contaminated ground, but this can now be largely controlled by

routine treatment with sulpha drugs, especially sulphamezathine, added to the mash or drinking water at the rate of 0·2 per cent. (about 1 oz. to 3 gals.). The new drugs sulphaquinoxaline and nitrofurazone are effective both for prevention and cure. With expert knowledge of nutrition, brooding may be carried out altogether in confinement, but there is less risk of failure to rear vigorous and healthy birds if they can have a spell on fresh clean grass. The farmer is much better able to provide clean land than is the specialist poultry keeper. Admitting the advantages of having the birds situated centrally near the homestead, it would nevertheless be best to start the brooding on clean land each season. Using general-purpose houses, the chickens can be reared each year on fresh ground and can be kept on in the same houses as layers and later on as breeding hens. If three sets of houses are in use, the hens will be out of the first ones in time to have them dismantled and re-erected on the new ground for the next brooding season. This may not be the most economical method of housing, and the wide scattering of the birds may make for laborious working, but it is a system which will enable heavy egg-production to be maintained with a minimum of losses. Even where the laying hens are centralized, brooding and rearing should certainly be carried out with the main object of ensuring the health of the stock.

Feeding.—Unfortunately it is not possible to ration fowls on the basis of the energy and protein values of the foodstuffs given in the Appendix. For one thing, foods are not equally digested by hens and ruminants, fibre in particular being of relatively little value to the former. Accurate rationing is also made difficult by the grazing and insect-eating habits of fowls, for it is only under intensive management that they are entirely hand-fed. However, it should be remembered that the hen has a limited digestive capacity and that she must not be given much fibrous food, such as bran, or her appetite will be satisfied before she has ingested sufficient nutrients. On the other hand, she can deal with a considerable amount of food like cooked potato, which is bulky only because of its high content of water. The heavier the production of eggs, the more the birds are likely to eat and the more important it is that the food should be in a concentrated form. Moderate restriction in feeding results in fewer eggs and not in loss of condition, and there are records of a 25 per cent. reduction in the food allowance causing the egg yield to drop to less than half.

Most of the food given to poultry consists of cereal grains and wheat-milling by-products mixed with a certain proportion of protein-rich material. Yellow maize and wheat are the best cereals; oats are poorer only in so far as they have a lower nutritive value; barley is good but not very palatable; rye is unpalatable. Rice and some other grains are satisfactory if they can be got cheap enough. Wheat bran, sharps, and middlings are all used for making up mashes, and about 20 per cent. of total wheat offal should always be included. Bran is very popular because it "lightens" the mash and perhaps because it is a little laxative; it is employed to satisfy the appetite where "forcing" is not wanted. The common protein foods are white-fish meal, meat-and-bone meal, skim milk and milk powder, and to some extent soya-bean meal and one or two other vegetable foods.

Mineral matter is of great importance in poultry feeding. Young chickens grow so rapidly that they require a great deal of lime and phosphorus for their frames; laying birds require large amounts of lime, as egg shells are almost pure calcium carbonate. It can be realized how big the risk of deficiency really is from the fact that a hen would have to consume 12 lb. of wheat to get enough lime for one egg. Common salt is another essential, but it must be given with care, as in excess it can be poisonous. Bone meal and steamed bone flour are used to supply calcium and phosphate; crushed oyster shell and small limestone chips are used to provide calcium.

Poultry, like other animals, require vitamins in their food. Vitamin A is supplied in plenty if the birds get green food or carefully dried greenstuff, such as clover or lucerne meal. Yellow maize (but not white maize) is another fairly good source of vitamin A. Most of the factors of the vitamin B complex can be got from green food (fresh or dried), milk products, and dried yeast. Vitamin B_{12}, which is a part of the "Animal Protein Factor," may be obtained from natural sources, such as droppings, earthworms, and grubs, but usually for breeding stock some animal protein is added to the diet to ensure good hatchability. Vitamin C is not required. Vitamin D must be supplied to young chicks that do not get direct sunlight or ultra-violet light, for without it they develop leg weakness. Green food contains very little of this vitamin, though sun-dried lucerne or grass meal is a good source. The usual means of providing a supply is to give tested cod-liver oil at the rate of approximately 1 per cent. of the ration

(1 pint per cwt.), but other vitamin-rich oils and irradiated yeast are also used. Laying birds do not need cod-liver oil except during the dull, short winter days, or where they are confined for long periods and all their light comes through ordinary glass. Special window materials are obtainable which allow ultra-violet light to pass, or open windows screened with sparrow-proof wire netting will serve the same purpose.

When antibiotics, such as penicillin and aureomycin, are included in poultry diets they normally have a stimulating effect on chick growth, but do not improve egg production or hatchability. As less than ¼ oz. of these antibiotics in a pure state is required per ton, great care must be taken to ensure thorough mixing with the food. Until more is known about the action of antibiotics, they should only be used in the rations of chickens and turkeys intended for the table.

Both soluble and insoluble types of grit are available for poultry. Insoluble (flint or gravel) grit enables birds to utilize their food efficiently, and where a natural supply is not available it should always be provided in addition to soluble (limestone or oyster shell) grit. The latter type of grit supplies the birds with calcium, but cannot be relied on as a grinding agent; and if this grit is fed alone (without insoluble grit), there is the danger that birds will consume excessive amounts in an attempt to obtain grinding material, thereby upsetting their calcium metabolism with adverse effects upon their health.

In rationing the birds, cereals are commonly ground to a coarse meal and thoroughly mixed with other foods, such as bran, meat meal, and salt, to form a "mash." The mash may be fed at intervals in a wet or crumbly condition, but owing to the trouble that this involves it is more common to feed it dry and to leave the birds with a constant supply. Kibbled maize or whole wheat or oats may be scattered on the ground, or preferably among the litter, to provide the morning and evening feeds. Feeding the grain in troughs is more hygienic where disease is prevalent and it has the further advantage of speeding up consumption during winter. Green food may be given fresh or in a dry form in the mash, but when the birds are on range they will obviously look after their own needs.

In chicken feeding the highest quality of materials should be employed and made up as a dry mash. Milk or milk powder has a particular value for the youngest birds. To begin with, the

mash is placed on boards and given about five times daily, but as soon as possible it is fed in hoppers. Water or milk is given to drink and green food forms a useful supplement. A common type of mash for young chicks is made up as follows: (1) 50 parts of yellow maize meal; (2) 30 parts of ground wheat or a mixture of bran and middlings; (3) 15 to 20 parts of protein-rich food including bone—say 8 parts of meat-and-bone meal and 8 parts of dried skim milk, *or* 2 parts of steamed bone flour, and as much skim milk as the chicks will drink; (4) 1 part of salt; and (5) 1 to 2 parts of tested cod-liver oil. In addition, fine oyster shell or limestone grit and fine pebble grit should be available in self-feeding hoppers.

From the time that the sexes are separated the protein-rich fraction of the mash should be reduced gradually. By the time the birds are ready to go on range the milk is stopped and the protein supply should be very small; steamed bone flour can be added to maintain the supply of phosphate. A liberal supply of protein was believed until recently to induce early sexual maturity, but it has now been shown that the effect is due not to the protein but to the mineral matter (chiefly salt) associated with proteins of animal origin. When the pullets are in their rearing quarters they may get more than half their food as whole grain, given night and morning. Their feeding should enable them to grow well and accumulate some reserve of fat.

The following table shows the approximate relationship between age, weight, and food consumption in chickens of dual-purpose type that are being reared as layers :—

Age in Weeks	Average Weight of Chick in lb.	Average Consumption of Dry Food per Day in lb.
0	0·08	...
1	0·11	0·02
4	0·4	0·05
8	1·2	0·11
12	2·2	0·17
16	3·0	0·20
20	3·7	0·24
24	4·3	0·25

Laying birds with some range on grass consume on the average about 4 oz. of food per day; birds in intensive houses may need

over 5 oz. Half of this is usually given in the form of a light feed of grain in the morning and a heavy feed of grain at night—the remainder being mash, provided in self-feeding hoppers. If hens in confinement are getting too fat, the protein- and fibre-content of the ration may have to be adjusted so as to reduce the proportion of carbohydrate. Cracked maize, wheat, and oats in various proportions form the grain or scratch ration, while cereal meal, wheat feeds, and fish meal or meat-and-bone meal form the mash ration. Most of the laying rations which have been shown to give good results contain about 10 per cent. of fish or meat meal, but less protein will suffice where the fowls are given an adequate supply of salt and other minerals; indeed, on good grass range there is no need to use a protein supplement, a cereal plus salt ration being all that is necessary. The amount of common salt required, in addition to limestone grit and green food, is about ½ per cent. of the ration.

The water requirement may be reckoned at 1 gal. per day for every 20 birds.

Table Poultry.—Cockerels of the light breeds are not worth fattening, but some may be used to supply the limited demand for *petit poussin*—birds of about a pound in weight. Early hatched dual-purpose cockerels can often be reared and sold at a profit, for there is a fair demand for spring chickens from March to June; but later in the season the surplus becomes heavy and prices tend to drop to an unremunerative level. The Christmas demand for high-quality poultry usually justifies the summer hatching of table birds.

Table chickens are frequently reared intensively for the first eight weeks or so and then run outdoors for a further six to eight weeks. They may be marketed directly off the run as "country" chickens; but if a better finish is required they should be brought indoors to a darkened building for fattening in crates, being fed a slop of Sussex ground oats and skim milk. This feeding period must be short—usually from ten to fourteen days—otherwise appetites flag, but an increase in weight of about ½ lb. per bird is normally obtained. Professional fatteners used to finish the birds by a further period of cramming, but this is no longer economic. Surgical caponization of table cockerels is now seldom practised, but similar results are obtained by treatment with female sex hormones, such as stilbœstrol or hexœstrol.

Intensive table poultry production has been started in England

on the lines of American "broiler" production. The "deep litter" system is employed, and at least three large batches of chickens are produced in a year, usually at an age of twelve to fourteen weeks. All the chicks in a batch are hatched at the same time and are reared together in one pen in a large house, allowing about 1 sq. ft. of floor per bird. These chickens are all marketed at one time, so that the house can be cleaned and rested in readiness for the next batch. The system is economical in labour and equipment. As the birds are kept in one house throughout, they are not upset by the frequent handling and changes of environment generally associated with more conventional methods of table poultry production. Where a highly concentrated, low-fibre, starchy diet, relatively rich in protein and including antibiotics, is fed to suitably bred chickens, birds weighing 4 lb. at twelve weeks of age, which have used less than 3 lb. of food to gain 1 lb. in live weight, can be produced.

As hygiene is so closely related to poultry husbandry, students are recommended to include the common poultry diseases in their veterinary studies. A bulletin on poultry diseases is published by the Ministry of Agriculture.

DUCKS, GEESE, TURKEYS

Ducks.—There are a good many breeds of duck, some of which have been developed for both table and egg-laying purposes while others have been selected primarily for egg production. An example of the former is the Aylesbury—a white duck with a horizontal carriage, a pinkish-white bill, and bright orange legs and feet; it weighs 9 to 10 lb. in the male and 8 to 9 lb. in the female. The Indian Runner is an example of the smaller heavy-laying type. There are black, white, and other coloured varieties. The carriage is very erect; the weight is about 4½ lb. in the male and 4 lb. in the female.

As compared with hens, ducks have a number of advantages. They are less prone to disease and remain profitable for about three years instead of two; they lay as many and in some cases bigger eggs; the ducklings are ready for market sooner than chickens and yet make heavier weights; they are cheaper to house and can be kept within bounds by quite low netting. On the other hand they have a few disadvantages. Duck eggs are liked by some people and sell readily in certain districts, but

because of their rather more distinct flavour they are not so generally acceptable as hen eggs. Another point is that ducks require at any rate 50 per cent. more food than hens. Again, they are much more easily excited, and through nervousness, rendered unthrifty and unproductive.

Ducks can be housed in most kinds of shed or building. They remain on the floor and lay their eggs on the ground, so it is desirable that the floor should be easily cleaned and at any rate the corners and sides should be well strawed. Special duck houses need be high enough only for convenience in cleaning ; a concrete or other impervious floor is an advantage. There should be 2 to 3 sq. ft. or more of space per duck and flocks should not exceed fifty.

Ducks lay batches of 20 to 40 eggs and then pause before starting again. For breeding they are mated in spring—four or five to a drake—and hens are frequently used to incubate the eggs, which take twenty-eight days to hatch. When well fed the ducklings grow rapidly and are fit to leave the hen soon after they are a fortnight old.

Ducks are fed on the same sorts of food as hens, but the mash is supplied in a much wetter condition and the grain is given in a shallow pan of water. When on free range the birds should be kept slightly short of what they will eat, so that they will forage well and secure the balance for themselves. Plenty of water, grit, and green food are needed if the range is restricted. Swimming water is unnecessary, but the birds enjoy it. Fattening birds must be kept away from water, otherwise they take too much exercise. Newly hatched ducklings are fed as frequently as possible, but after eight weeks they will do on three meals a day. Adults on range need be fed only twice daily.

Geese are kept primarily for their flesh. The birds feed largely on grass and do best when given an unlimited range of pasture. In practice mash should be fed up to the age of six weeks, and again for a fattening period of about four weeks. During the intervening period they do well on pasture alone. In spring the numbers are built up to take full advantage of the grazing season ; by Christmas the young geese have been marketed and the flocks reduced to the breeding birds. Geese live for a long time and have been known to lay for twenty successive years ; they are very hardy.

For table purposes a carcass of 6 to 9 lb. is in demand, and this can best be got from the smaller breeds such as the Chinese

and the Roman, which weigh 10 to 14 lb. when full grown. Large geese—weighing, according to the breed, 20 or 30 lb. as adults—are rather too slow-maturing and coarse for modern requirements.

Geese do not make much use of houses, so these for small numbers can be very simple. Large flocks, however, should be locked up at night in roomy and well littered houses. For mating, a male is allotted to three females of the heavy breeds and up to five of the smaller sorts. Eggs are laid from February onwards, the number for the season being 20 to 80 according to the breed and the individuality of the bird. The incubation period is thirty days and the eggs are normally hatched by hens, which can cover 4 eggs. An alternative plan is to start the eggs in an incubator and transfer these to hens after a week or two. The young goslings require to be fed at least five times daily, but they soon become independent, and if it is not too early in the season can do without heat after a fortnight. After about a month three feeds will suffice, and later on, when the birds are grazing hard, one feed per day is enough; indeed "green" goose is fattened on grass alone. However, in autumn, when the pastures are getting bare, birds that are being fattened for the Christmas market should have as much food as they will clean up twice a day. About 3 oz. of concentrated food per day is sufficient for a goose on grass during the breeding season. Geese consume the usual poultry mashes and grains, the latter being given in shallow containers of water; they also take chopped greens, boiled potatoes, and kitchen scrap.

Turkeys, like geese, are kept because of the high quality of their flesh, and most of them are reared for the Christmas trade. The birds are heavy: in the case of the well-known American Mammoth Bronze a mature cock weighs from 30 to 40 lb. and a hen 18 to 26 lb.; cockerels and pullets for table purposes generally weigh 20 to 25 lb. and 14 to 20 lb. respectively. Their breeding life is four to six years.

Turkeys are much less hardy and resistant to disease than are geese, particularly when they are young. They do best when kept on well-drained soils with abundance of room and the natural shelter of woodlands, and away from ground that has been soiled by other poultry. They require perches but may be housed in rough sheds if the situation is sheltered; they roost readily in trees. The hens tend to lay in places like hedge bottoms, so baskets or boxes—or old barrels on their sides—may be fixed in such sites to serve as nests.

The hens begin to lay in March and produce two clutches of 18 eggs or more. A male is allowed from 10 to 15 hens and one mating fertilizes a full clutch. If only 2 or 3 hens are kept the male should not be left with them all the time or he will pester them. The eggs from at any rate the first clutch are removed and placed under hens, or hatched in incubators, and the young reared in artificial brooders. The eggs take twenty-eight days to hatch. Sometimes the turkeys are allowed to incubate their second clutch, but when sitting they are not very amenable to handling.

Adult turkeys are fed on mashes and grains similar to those used for other poultry, and considering their size, they are not heavy eaters. The birds are fond of insects and worms, and when they have a good range, 5 oz. of concentrated food per day will meet their requirements. Young turkeys require mashes with a much higher protein-content, and considerably more vitamin A and vitamin D than those commonly fed to chickens. Newly hatched turkeys tend to have poorly developed instincts and often require training to eat and drink; after the first week they may get five feeds, then four, and from the tenth week onwards three will do. Fattening birds will be of the best quality if they can be finished on meals and separated milk.

PART IV

FARM ORGANIZATION AND MANAGEMENT

CHAPTER I

LAND AND ITS EQUIPMENT

THOSE who choose farming as a vocation do so for various reasons. To make a living, or a financial profit, is very often the chief motive, but it is rarely the only one. Many people, indeed, find in farming satisfactions that cannot be measured in terms of money or material things. In this book, however, we are concerned not with farming as a complete way of life but only with its technical and business aspects.

It has often been pointed out that technical skill in the production of crops and live-stock products does not of itself ensure financial success in farming. Such success depends also upon competence in the organization and management of the farm as an integrated business. Such competence derives partly from personal qualities—for example, the gift of inspiring the confidence and winning the co-operation of the farm staff, and the inborn powers of judgment that are required in weighing alternative plans and reaching sound decisions. But it is also true that management, to be successful, must be based upon economic and business principles, and it is these principles that form the subject-matter of this section.

Something must first be said about the various particular objectives that farmers, according to their varying circumstances, may have in mind, and about the origins and development of our present-day farming systems in this country.

Agriculture, which dates from early neolithic times, was originally adopted as a more reliable way of securing the necessities of life than the older economy which was based on hunting, fishing, and the collecting of seeds, roots, etc. The early cultivating peoples grew such plants as cereals, pulses, roots, and other vegetables for food, and cultivated flax, cotton, or some other fibre plant for clothing. They built their huts out of the most easily available materials, thatching them in many cases with cereal straw. They made household utensils out of flint or other

minerals, wood, and moulded clay. The early stockmen lived on meat, milk, and various milk products. They used for clothing and for tents either skins or else felted or woven cloths made of wool or hair. The early mixed farmers, by a combination of crop and animal husbandry, achieved a more varied diet, eased their burden of work by harnessing cattle to their implements, and in some cases at least, discovered in animal manure a means of maintaining the fertility of the soil. The first farmer immigrants into Britain, who arrived about 4500 years ago, possessed cattle and sheep, and cultivated barley, wheat, beans, and flax.

These various forms of ancient subsistence farming were common in many parts of the world until comparatively recent times, and they survive in places at the present day.

The next stage was the emergence in each little community of a relatively small class of specialist craftsmen—the smith, the potter, and the weaver, and, later on, the joiner or builder, the miller, the shoemaker, and others. In such communities each craftsman provides some particular service and is paid in kind—largely in food. Generally there is a very limited amount of long-distance trade, restricted to such metals or other necessary raw materials as are not locally available.

This form of economy, in which the village or other small community is substantially self-supporting, prevailed in most countries throughout mediæval times, and it persists to-day, with only minor modifications, over large parts of India, China, and other countries. Normally, under such conditions, about four out of every five families devote the major part of their energies to food production, though the farmers' womenfolk spin, collect and prepare fuel, brew, etc. Conversely it is usual for the specialist craftsman and his family to cultivate a small piece of land and produce part of their food. In other words, the separation between farming and manufacture is only partial.

The early development of "commercial" farming—the production of food for sale—was associated with the development of cities. Thus the concentration of a large urban population in Rome created a market for large quantities of agricultural produce, and led to the setting up of "commercial" farms producing wheat, olive oil, etc., for cash sale. Again, so far as this country is concerned, the earliest cash farmers were concerned with the feeding of London, which long remained the only large town. Originally London's citizens, like those of other towns until

much later times, combined farming with other concerns, cultivating pieces of land outside the city walls and keeping cows that daily walked out to near-by pastures. But as London grew, the adjacent lands came to be needed for the production of perishables, like vegetables and milk, so that non-perishable foods had to be drawn from farther afield. By the seventeenth century, butter was being brought by pack-horse from the Vale of Aylesbury and Suffolk. Cheese, produced in the Wiltshire Vale, was taken overland to the Upper Thames and thence to London by barge—some even came from Cheshire by sea. Wheat and malt were brought by coastal shipping from East Anglian and south coast ports, and also by barge from the Upper Thames Valley. Fat stock was driven on foot, in summer and autumn, from as far as Norfolk and Leicestershire. By this time, therefore, some farmers in many parts of the country were looking more and more to a distant market for a cash income, were specializing in the particular crops or live-stock products that would procure them the largest cash incomes, and were thinking less and less of their land as the direct source of consumption goods for their families. But these were still a small proportion of the whole.

Another early development of "business" farming, with more pronounced specialization, was the cause of a great popular outcry in Tudor times. This was the replacement of the old system of subsistence farming by a cash economy based on the production of wool for export. The object was to acquire foreign exchange for the purchase of imports—chiefly luxury goods like silks, other fine textiles, wines, and spices. The main grounds of the popular complaint was not the diversion of land from food production, for it seems that agricultural improvement, at the time in question, was more than keeping pace with the slow growth of population. The serious concern was over the wholesale depopulation of the areas concerned. These areas were largely the chalk and limestone uplands of the south-eastern half of England, though the sheep business was found elsewhere—for instance, the monks of the great Border abbeys had extensive sheep farms in the Cheviot Hills. This type of farming, like farming for the London market, was restricted to relatively small parts of the country, but it was of great importance as the basis of overseas trade. Up till the fifteenth century the chief export was unmanufactured wool, but as time went on, most of the home produce was worked up, by cottage spinners and village weavers, into finished cloth.

The widespread changes that constitute the industrial and agricultural revolutions had gained considerable momentum by 1760 and continued for the greater part of the following century. One impelling reason for the reorganisation of farming was the unprecedented increase in population, arising out of the fact that the death rate, especially among children, had been markedly reduced through the progress of medical science. The population of Great Britain roughly trebled in the hundred years, and since there was still no source of substantial food imports, more intensive cultivation of the country's soil was imperative. The period was one of large-scale reclamations of moor, marsh, and forest. Also, with the objects of higher production and improved efficiency, the old open-field manors of eastern England and the Midlands, with their scattered strips of tillage land and their very unproductive commons, were replanned, enclosed and converted into farming units of a size that would admit of economic commercial production. A similar process occurred on the old townships of Lowland Scotland. New crops—potatoes, roots, and clover—were introduced; phosphates, derived from bones and coprolites, were applied with astonishing effect; towards the middle of the nineteenth century the invention of the drain-tile was exploited on an immense scale on the heavier and wetter lands; nitrogen fertilizers such as guano, Chilean nitrate, and sulphate of ammonia were introduced about the same time. All these efforts were indeed not enough for full success. There was serious dearth in the eighteen-forties, but the achievement was immense.

The other great change of the times was the concentration of manufactures with the object of utilizing water and, later on, steam power, and otherwise exploiting mass-production methods. Spinning and weaving, which had formerly been carried on in cottages in the agricultural districts, moved to the Yorkshire dales and other regions where water power was available, and where, in many cases, the adjoining land was poor. Iron smelting—formerly carried on in small units in forest country—moved, as coke replaced charcoal, to the coalfields. The introduction of the steam engine greatly increased the demand for coal, with a consequent increase in the number and size of mining villages. Thus a large proportion of the people ceased to have any concern with food production, while the remainder gave up their industrial activities and concentrated on agriculture. Hard roads, canals,

and later railways were built to carry the vastly increased amount of long-distance traffic between farm and city.

It was inevitable, under these circumstances, that little farms and small holdings should have been thrown together to make big farms; the old small-holders, having formerly lived partly by cottage industries, had not enough land to provide a living by farming alone. It was natural, too, that the old system of farming, producing "a bit of everything," should give way to more specialized forms. Thus Cheshire, Ayrshire, and the Somerset Vale took more and more to cheesemaking; the heavy-land farmers of Essex and Suffolk specialized in wheat; the light arable farms of the Eastern counties concentrated on grain and winter meat. Similarly, Kent expanded her orchards, and Aberdeenshire, especially after the invention of steamships, set out to supply the London demand for choice-quality beef. The Scottish mountains specialized — probably over-specialized — in sheep.

But the changes were not everywhere so marked or so complete. Devon and Cornwall were already, before the revolution, laid out in small farms of enclosed fields, and they were too far from the new manufacturing regions to attract the attention of the new type of business farmer. In many Midland areas the enclosure and redistribution of the village lands was done in a half-hearted fashion, so that many farms to-day consist of separate bits and pieces. In Wales there was no wholesale change such as occurred in the West Highlands of Scotland; the holdings remained small and the mountain sheep-walks continued, in many cases, to be held in common: part-time holdings persisted in Yorkshire, Lancashire, and elsewhere in the vicinity of the scattered wool and cotton mills.

Another fact is that specialization to the point of monoculture—the concentration upon a single crop—has never developed on any considerable scale in this country. This has proved a wise limitation, for the general experience of such systems—*e.g.* "bonanza" wheat farming in western North America, cotton farming in the southern United States, sugar-cane growing in some of the West Indies—has shown that one-crop farming is rarely successful in the long run. In some cases the breakdown has resulted from soil erosion or exhaustion, in others from epidemic plant disease; sometimes from a fall in demand for the single commodity produced, and sometimes through a combination of these and other factors. Apart from the advantage of producing more than one cash product, it has often proved wise to retain an element of

subsistence farming alongside the commercial enterprises. Thus even the farmer who relies mainly on sugar-beet, grain, and beef for his money income may well provide directly his own family's needs in the way of milk, eggs, poultry, bacon, potatoes, and other vegetables. The best balance between the two types of production depends on circumstances; in general, subsistence production should be relatively important on small farms that produce only one or two commodities for sale and employ little or no paid labour.

Up till the thirties of last century this country remained substantially self-supporting in regard to food. It is true that standards of nutrition, especially in the industrial towns, had become far from adequate; partly by reason of the irrational preference for white bread, but mainly because of inadequate supplies of " health foods "—milk and dairy products, meat, eggs, and fresh vegetables. The food situation deteriorated during the forties—partly because population continued to rise after the reserves of cultivable virgin land had been largely exhausted and partly on account of bad seasons and the outbreak of potato blight. The repeal of the Corn Laws (1846) marked the recognition of the fact that the country would for the future require substantial imports of staple foods.

It was not, however, until thirty years later that British farmers felt the weight of overseas competition in the home food market. Wool was the only important product which other countries could deliver in British markets at a substantially lower price than that which home farmers had considered profitable, and the situation was at least partly met by a change of emphasis, from wool to meat, by British sheep breeders. British farming in the fifties and sixties attained as high a level of efficiency and intensiveness as was to be found anywhere in the world, and tenant farmers, despite high rents, earned large profits.

But the invention of the reaper and later of the string binder (1878) together with the building of a railway network over the North American Continent changed the situation. Wheat prices, especially, dropped to unprecedentedly low levels — ultimately falling, in the early nineties, to a level of about five shillings a hundredweight. This change caused a major financial crisis, marked in various parts of the country by bankruptcies of tenants and the failure of landowners to find others. Naturally the crisis was most acute in the clay-land areas that had been devoted largely

to wheat production. The depression spread to other areas with the commencement, in the last decade of the century, of large-scale imports of frozen meat. Most other European countries met this situation by heavy import duties on grain and other foodstuffs, taking the view that the preservation of their agriculture was more important than a lowered cost of living for the urban population. This course was not without its disadvantages, tending on the one hand to perpetuate obsolete methods of farming and on the other to handicap manufacturers in competition for the export markets that the new countries provided.

In any case, British farmers worked under great difficulties in the thirty years that began with the disastrously wet and cold season of 1879. Much of the poorer land, especially in the uplands and the clay countries, was left to tumble down to poor pasture. Rents fell, and buildings, drainage, and other equipment deteriorated, while the number of farm workers greatly declined. In some areas, indeed, a solution was found in switching production to such commodities as milk, potatoes, vegetables, fruit, poultry, and eggs, which, with the rising real incomes of urban consumers, were in increasing demand. Milk displaced wheat as the most important product of British agriculture.

Scarcity of goods and currency inflation towards the end of the first World War led to high prices and large farming profits; but prosperity was short-lived, and subsequent losses very quickly outweighed the gains. The period between the wars was again one of depression, but the underlying causes were essentially different from those which had operated in the eighties and nineties; British farmers now suffered in common with those of other countries, and many groups of manufacturers. Agricultural depression was, in fact, more acute in many overseas countries, including Canada, Australia, and the United States, than in Britain. Indeed some British farmers were in a position to take advantage of the situation by expanding their dairy, pig, and poultry enterprises through the increased use of imported feeding stuffs, which were in plentiful supply at very low prices.

The outbreak of the second World War, with the prospect of something approaching siege conditions, forced a major change in the whole structure of British farming. The emphasis was naturally placed on the essential foods—cereals, potatoes and other vegetables, sugar-beet, and milk—and the tillage area was greatly expanded. By a combination of price incentives, appeals

to patriotism, recruitment of women workers, rationing of scarce raw materials and equipment, the provision of various services by County Committees and other means, production was raised to a level that surpassed the highest expectations.

A number of dietary surveys, carried out in this and other countries during the inter-war period, showed that, despite the low prices and apparent surpluses of many foodstuffs, a large proportion of the world's population were inadequately fed.

In 1943 the United Nations Conference on Food and Agriculture, which met at Hot Springs, discussed the long-term problem of achieving adequate levels of nutrition and made a number of important recommendations.

The chief grounds for anxiety about future food supplies appeared to be: (1) the continuing rapid increase of world population, (2) the approaching exhaustion of the once large reserves of fertile virgin land, (3) the high rate of wastage of soil resources by erosion, and (4) the magnitude of the gap between the food supplies and the nutritional requirements of the world even before the outbreak of the second World War.

The conference recommended a large number of long-term measures designed to mitigate the situation. Among these were: (1) the expansion of agricultural research, educational, and advisory services, (2) the provision of better facilities for the supply of capital to promote the expansion and improvement of agriculture, (3) the provision of fuller security of tenure for farm tenants, (4) measures for the control of prices at such levels as might be expected to encourage the expansion of production, and (5) measures to prevent erosion and other forms of wastage of soil resources.

Since the end of the second World War national agricultural policy has been directed towards overall expansion of output, with emphasis on those commodities that seem likely to be in short supply in accessible world markets and on such as can be produced in Britain of good quality and at relatively low cost. In the year 1952-53 the agricultural output of the United Kingdom reached a level of 51 per cent. above the average of the period 1937-39.

* * * * * *

The agents that are used in agricultural production are land, capital (including buildings and other "improvements,"

implements and machinery, animals, seeds, manures, etc.), and labour. The land may be utilized in various ways—as, for instance, arable, pasture, meadow, orchard, or woodland. Capital and labour may be applied in varying measure, intensively or extensively, as we say. Crop produce may be marketed as such—*e.g.* wheat or potatoes—or may first be converted into animal products—*e.g.* roots and straw used to produce meat. Sometimes material must be purchased to permit of the profitable disposal of home produce—as fish meal to make possible the efficient utilization of unmarketable potatoes. Sometimes it may happen that a single enterprise, like wheat production, apple growing, sheep breeding, or milk production, may constitute in itself the most economic system of farming for a given set of conditions. More frequently the most economical employment of land, labour, and capital can be achieved only by dovetailing together a number of distinct enterprises.

How to use land; how to equip it; what crops to grow and how to dispose of them; what labour to hire and how to employ it—all to the end of maximum net profit, and having regard to all the local conditions—such is broadly the problem of organization.

LAND

Land, the first essential agent of production, varies in quality and in value. Its value depends not only upon the original nature of the soil, the climate, etc., but also upon any improvements in its condition that have been made by human agencies as well as its situation in regard to supplies of raw materials and its accessibility to markets for its produce. The measure of its value is the true or economic rent, *i.e.* the income it is capable of yielding over and above the usual return on capital and the usual rewards for labour and skill in management. The theory of economic rent is that the poorest or the least accessible land that will be used for agriculture is such as will only just repay the application of capital and labour, but will leave no margin. Such land may be said to be "on the margin of cultivation," or simply "marginal." Any land that is more fertile, or more accessible to markets, will produce a return over and above the current return to capital and labour, which surplus constitutes "economic rent." The rent that a piece of land will produce cannot, however, be determined without reference to the amount of capital and labour applied to

it. The kind of land that is just worth farming, and the degree of intensity of cultivation that it is worth while to apply to land within the margin of cultivation, will change with changing economic conditions. Thus in the middle of last century much poor and heavy land in Essex was growing corn, while thousands of square miles of prairie, capable of growing better wheat with less labour, were lying idle. A rise in wages coupled with a lowering of transport costs reversed the position, and the prairie lands were broken up while Essex farms fell derelict. But later, owing to other changes, such as a growing world demand for wheat and the development of the London milk market, these farms again came within the margin of cultivation.

The conception of fertility is a composite one, implying an estimate of the quantity and quality of produce that the land is capable of yielding in relation to the amount of human effort expended on it. Fertility depends on a great variety of circumstances, such as the presence of plant foods and the absence of plant poisons in the soil; the behaviour of the soil towards moisture; its ease or difficulty of cultivation; the amount, regularity, and seasonal distribution of the rainfall; the temperature conditions, sunshine, etc. It will be obvious that there can be no permanent measure of fertility, because progress in agricultural technique affects the potentiality of various types of land in very different ways. For example, the discovery of the use of lime or of potash; the invention of tile drainage or of tractors; the introduction of the potato or of wild white clover—all these and many other steps in the progress of agriculture have brought about changes in our estimates of the relative values of different lands. Not only so, but estimates of fertility change from time to time and from place to place with changing economic conditions, as witness the Downs and the Fens in prehistoric as compared with modern times; at present the Fens are incomparably the more fertile, yet we know that the high, thin, chalky soils were the first to be brought under cultivation, while the fen lands were almost the last. Before the age of railways, relatively poor sandy land within wagon-range of London had a high value because, with the ample available supplies of city stable and cowshed manure, it was suitable for the production of vegetables and soft fruit which could not be transported from far afield; at the time in question land in Bedfordshire, now used for vegetable

production, was still farmed on the sheep-and-barley system and commanded only a small rent. The development of rail and later of lorry transport, together with the growth of London markets, resulted in the development of market gardening in Bedfordshire and, later on, in the silt lands of Lincoln and Norfolk.

Again, between 1880 and 1939, a large area of clay land, once devoted to rather intensive cereal production, was laid away to grass and fell greatly in value. More recently the development of power tillage, with a consequent reduction in costs, together with a recovery in cereal prices, has favoured a change to corn-and-ley farming.

Under nature every piece of land has a certain type of flora, the resultant of the soil and climatic conditions. Thus we may distinguish between steppe or prairie, moorland, natural forest of various types, and many others. Moreover, each type of flora supports a particular type of fauna.

Agriculture, in the widest sense, may be said to include all schemes that are employed by man in order to increase the usefulness to himself of the plant and animal life that the land supports. Such interference may be slight, consisting, for example, of nothing more than the aiding of useful species of plants and animals by attacking their natural enemies (game preserving, forest conservation), whereas in its final stage agriculture aims at the complete suppression of the greater part of the natural flora and fauna (weeds and pests), and substitutes one or more selected species, which are modified and cared for in order to develop their maximum usefulness. The larger the human population to be supported and the greater its wants, the greater will be the extent of our interference with nature, *i.e.* the more intensive will agriculture become.

Lands are classified, from the agricultural point of view, according to the product for which they are specialized, thus :—

1. *Game and Fishing Preserves.*—Wild animals under some degree of protection.
2. *Forest.*—Trees grown for timber, bark, etc., where utilization involves felling.
3. *Orchards and Plantations.*—Trees or other perennial plants for fruit, leaves, latex, etc., where utilization does not involve felling.

4. *Garden and Nursery Lands.*—Plants requiring or repaying highly intensive treatment, individual care, etc.
5. *Farm Lands*:—
   (*a*) Pasture—perennial herbaceous plants, grazed.
   (*b*) Meadow—perennial herbaceous plants, mown.
   (*c*) Tillage—plants propagated annually.

The boundaries between these different classes are, of course, not hard and fast. Thus between farm and garden, garden and orchard, etc., there is an insensible gradation among cultural schemes. Moreover, two purposes may be combined, as in the case of hill grazings that are also grouse moors, or orchards or woodlands that are also grazings. Again, among farm lands we find many that are worked on a system of alternate grass-and-arable husbandry. The first problem of organization is to allot the land to the particular purpose for which it is best suited, *i.e.* to whichever mode of utilization is likely to produce the largest net return. Taking the various types in the foregoing order:—

Game, from the fact that it is kept in the wild state, is capable of yielding only a very low gross return measured in actual produce. Hence it can only become the most profitable product either where land is of very little value for other purposes (*e.g.* mountain or heath), or where, in wealthy communities, there are people who are prepared to pay relatively large sums in order to gratify their desire for sport. Generally, the two conditions must occur together before any considerable amount of land will be set aside exclusively for game—*i.e.* there must be both a supply of low-valued land and a considerable demand for sporting rights.

The preservation of game on land that is being used for another purpose—whether forestry, agriculture, or horticulture—generally reduces its value for such other purpose; moreover, game animals, since their feeding is not under control, are capable of doing an amount of damage that is quite out of proportion to the amount of food they consume—*e.g.* when they attack crop plants in the seedling stage. Some species that are valued as game are, however, either harmless or actually beneficial. The partridge and the quail feed mainly on weed seeds, and their preservation interferes with farming only in that a certain amount of nesting cover must be provided. Where there is a good demand for sporting rights

a certain amount of game may pay, *i.e.* may add to the net value of the land even if some damage is done. The amount that is permissible depends on the system of utilization that is being applied. In general, the more intensive the cultivation the less place is there for game: thus on our mountain grazings the preservation of game is often very profitable; on the better sort of grasslands, in established woodlands, and on the less intensively worked types of mixed farms, it may be quite in place; whereas, under intensive arable conditions, and still more in gardens and nurseries, game (except partridges, etc.) must be reduced to a minimum.

Forest Lands, of which timber is the chief product, are dealt with in various ways, and produce forests of many different types. One outstanding feature is, of course, the long period that is required for trees to mature, or even to reach such a size as to enable them to be utilized at all. Forty, eighty, or even considerably over a hundred years are common lengths of rotation. This implies, almost unavoidably, a relatively high capitalization; for even if we suppose a small figure for planting, etc., and a low annual rental of the land, the initial and current charges, lying out at compound interest over such periods, eventually grow to very large sums. Again, the produce of "cultivated"—*i.e.* of planted and tended—forests has had to compete in the past with that of natural forests in various parts of the world, so that the gross income has been limited. As the world's forest reserves have been depleted, the price of timber in relation to the general level of prices has risen. On the other hand, it is impossible to predict the extent to which, in the course of fifty or a hundred years, other materials—such as steel and concrete, or plastics—will be substituted for timber. Under existing conditions it is only where land has a low agricultural value that forestry can be an economic success. If, for example, a piece of land is worth, as grazing, 5s. an acre of annual rent, it will be doubtful, even if it is fairly well suited for afforestation, whether forest could give as high a return. The Forestry Commission, which is in control of State afforestation in Britain, has acquired most of its land at prices below £4 per acre, whereas ordinary farm land, worth perhaps £20 to £30 per acre in 1939, had risen, at the time of writing, to about £50 to £80.

On the other hand is the fact that many forest trees have, as compared with practically all agricultural and horticultural crop

plants, very low requirements for soil nutrients. Also, since land under forest requires no tillage, trees can be grown on steep or rocky ground which cannot profitably be farmed. Hence timber can be produced with success on land whose only alternative use would be as rough grazing. Again, forestry can be successfully practised on slopes so steep that they would be subject to soil erosion under any form of agriculture, not excluding grazing. In countries where erosion is a serious problem, large areas of eroded land are being reafforested. Forests employ relatively little labour and require little equipment—circumstances that give forestry a place, along with sheep and cattle ranching, under extensive conditions, *i.e.* where land is cheap in relation to the other agents of production. Timber is costly to transport by land but cheap to carry by water, so that proximity to rivers, etc., is an important consideration. Trees are more liable than are agricultural and other crops to destruction by wind and fire, and the amount of risk and the possibilities of protection must be taken into account in deciding for or against afforestation.

There are a few exceptions to these broad facts—*e.g.* the timber of the cricket-bat willow, when it is of high quality, is very valuable, and the production of high-class material requires a highly fertile soil. Moreover, the trees reach maturity in a comparatively small number of years.

In so far as concerns particular areas, forestry should be regarded as an alternative to agriculture. There are, it is true, woodlands that have a certain grazing value, but such combined utilization is rarely economic. The feeding of pigs in forests of oak, beech, Spanish chestnut, etc., is an exception, making possible the utilization of a valuable by-product without disadvantage to the forest itself.

If, however, we have in mind not individual plots of ground but large districts, we may find that farm and forest are not alternatives but are economic complements one of the other, *i.e.* a suitable allocation of land to each will produce a higher average return than could be obtained from either by itself. This may happen even when the land within the area does not vary sensibly in quality. Examples are to be found in regions where transport is expensive or difficult and where the population has to depend mainly on local produce. Here the farm lands produce the materials for food and clothing, the forest those for house and

fuel. Again, in many of the colder parts of the world, agriculture provides full employment during only part of the year—the frost-free period—whereas in forests the greater part of the work, including felling and disposal, can be done in winter. Thus the two industries together can employ labour more economically than could either alone. The British Forestry Commission, in connection with its afforestation schemes, creates numbers of smallholdings and guarantees a certain amount of employment in forestry to its tenants.

Woodlands may also, in certain cases, be properly regarded as minor adjuncts to farms, being maintained for the purpose of producing the quantity of timber necessary for fences and the like. In exposed districts, woods in the form of shelter belts may be of very considerable value to the farm, and in hot climates trees are useful for the provision of shade for live stock. In such cases timber production becomes a secondary consideration. The provision of cover for game is a further use of woodlands, and is one that need not greatly interfere with their main purpose.

Orchards and Plantations other than of timber trees (*i.e.* sugar-maple, rubber, coffee, nuts, etc.), resemble forests in so far that they are formed of perennial plants that usually require to stand for a period of years before they begin to yield. They have thus the same general feature of a high capital requirement. The productive stage is, however, usually reached a good deal earlier than in the case of forests; moreover, the yield of the individual trees is sustained over a number of years, and tends to remain fairly constant from one year to another. Orchards, etc., also differ from forests, and resemble garden lands, in that the labour requirement—for spraying, pruning, harvesting, curing, and packing of the produce—is high. In many cases cultivation of the soil is necessary or desirable, so that there must be no serious obstacles to tillage; but since this tillage is normally not very intensive, great ease of cultivation is not essential. Many of the products of orchard lands, unlike timber, carry away considerable amounts of manurial substances, so that the soil should generally be chemically fertile. Wind shelter and immunity from spring frost are also important. "Frost pockets" occur where cold air (being heavier than warm air) flows downhill and forms pools in hollows. Moreover, hedges and shelter-belts can act as "dams," preventing air drainage. The siting of orchards must,

therefore, be based on a careful survey of air-drainage conditions. Considerable depth of soil is necessary to provide a sufficient reservoir for rain water, and adequate drainage is important. Capitalization, current charges, and gross returns per acre all tend to be higher in fruit-growing than in ordinary farming, and the yield and quality of the produce are at least as dependent on soil and climate as are those from annual crops or grass. Land suitable for fruit-growing often commands a rent or a price which could not be paid by the ordinary farmer.

Market Gardens may be regarded as the more intensively worked types of arable farms; the kind of crop, a plant propagated annually and grown in pure culture, is essentially the same; the chief difference is that the gardener confines himself to those species or varieties which, because of their capacity to yield crops of high value per acre, repay more intensive cultivation and individual treatment, whereas the farmer is restricted to such as are fairly robust growers and can be dealt with by cheap wholesale methods. Many crops—such as potatoes, carrots, peas, celery, and cabbages—are common to both systems, and many holdings are cultivated on a system intermediate between the two. Moreover, large scale "farming" methods have in many cases been successfully applied to crops (*e.g.*, green peas and carrots) formerly grown on a "garden" system. Much garden produce is perishable, or at least has a maximum value when quite fresh, whereas farm crops and their products can generally be stored for considerable periods and can be handled and marketed in quantity and cheaply. Then, also, all garden stuff is intended directly for human food, whereas much farm produce is converted by live stock into secondary products.

One outstanding feature of the market garden is, of course, its high labour requirement. Few farms, apart from the transition type of holding mentioned above, employ more than four or five persons per hundred acres, whereas in market gardens the labour may rise to one person per acre, or with glass, etc., far higher. The capital investment, apart from glass, is not proportionately high, chiefly because the rate of turnover is very rapid.

In respect of physical conditions, the gardener's crops are by definition of a less robust type than those of the farmer. Moreover, one of the main objects of the market gardener is to produce, as nearly as may be, a regular supply of fresh material

at all seasons of the year. These facts both point to the selection of land so situated that the growing season reaches the maximum length for the locality and where the climate is relatively mild and equable. Hence in Britain a low elevation, proximity to the sea, a southern exposure, and shelter from winds, are all of importance. For the same reason the soil should be of a warm, early type, *i.e.* light and well-drained. The last point has a double importance, for, since a succession of supplies must usually be aimed at, the soil must be of such texture that it can be worked, and a tilth secured, at many different seasons and under many different weather conditions; it is true, however, that modern methods of preservation—particularly deep-freezing—are tending to reduce the importance of a succession of supplies. The heavier the soil the more is the cultivator restricted as to his time of seeding. Moreover, stiff clays, even at the best, can scarcely be got into the state of tilth necessary for the smaller-seeded and more delicate of the gardener's crops. Chemical fertility is to the gardener relatively unimportant. His costs are so high, mainly owing to the large amount of labour employed, that even very intensive manuring involves only a relatively slight addition to the total. At the same time it must be borne in mind that the lightest sands cannot be successfully worked unless organic manures, as well as artificials, are available. Without the former the moisture supply will be liable to fail, growth will be interrupted, and the quality of the produce will suffer. The use of catch crops for green manuring is one method of meeting the growing shortage of stable dung, which was formerly the commonest form of organic manure.

The ultimate form of intensive gardening is, of course, cultivation under glass, *i.e.* with both a climate and a soil that are very largely artificial. In this case most of the physical conditions are under control, and the natural quality of the land loses its importance. The cost of heating, however, is relatively high in cold climates and exposed situations and winter sunlight is of great importance.

Probably more important than any of the natural conditions is the economic situation of the land, *i.e.* its proximity to markets, the amount of competition from other industries for the available labour, and the state of development of means of transport and of methods of marketing. Hence market gardening originally tended to become concentrated near centres of population. In

recent times more rapid transport and low-temperature storage have worked towards a wider diffusion of the industry. Thus London's supplies of vegetables were mostly produced, up till about 1850, in the zone within a night's journey, by wagon, of the city. With the coming of railways, vegetable production spread on to suitable land, in Bedfordshire and elsewhere, as far as 50 or 60 miles out. Still later, mechanized road transport, permitting direct movement from field to market, led to a further widening of the zone, *e.g.* to include the silt areas of south Lincolnshire. Air transport obviously provides further possibilities, at least for such commodities as have a high money value in relation to their weight. It will be obvious that the increase in population of the world will tend towards the increase of garden at the expense of arable farm lands, just as it will cause grassland to be broken up for arable farming.

Nurseries devoted to the propagation of perennial plants (*e.g.* fruit and forest trees) are akin to gardens in their high labour requirement, but are found under a greater variety of soil and climatic conditions. They tend, however, to be established on the more easily tilled soils and under the more favourable climatic conditions.

Agricultural Lands include pastures, meadows, and arable fields. If the cultivator allocates a given area for an indefinite period to one purpose or the other, we speak of "permanent" pasture, meadow, or arable, but it will be obvious that no scheme of allocation, if it is to depend on economic considerations, can be truly permanent. Changes in the distribution of population or developments of transport methods may, and frequently do, force the breaking-up of grassland in one area and the laying down of arable to grass in another. Improvements in methods of tillage, or in the techniques of pasture production, and many other causes, may have a like effect in one direction or the other. The alternative to such "permanent" allocation of the land is to adopt some scheme whereby the land is put under tillage and grass during alternate and more or less definite periods of years. The three possible systems are therefore: (1) permanent grass (including both pasture and meadow), (2) permanent arable, (3) alternate husbandry; and it is necessary briefly to set down the main considerations that should guide the farmer in deciding for one or the other.

1. In the first place, the gross return from arable land, measured

in terms of quantity of human food, etc., is generally higher than from grassland. Broadly speaking the money value of the output is also higher; but the most intensive forms of grassland milk production, with heavy fertilizer usage, frequent re-seeding, strip grazing, and grass drying or ensilage, gives as high gross returns as all but the most intensive forms of arable cropping. But in general, arable farming is the more intensive system of the two, and will, other things being equal, tend to prevail wherever the land is fertile and of easy access to markets. The less fertile or the less accessible the land the more will it tend to be left in grass. Land that falls below a certain level of fertility, whether owing to a short growing season, insufficient warmth or rain or sunlight, or to chemical or physical deficiencies of soil, will fail to leave any net return under arable farming. Similarly, at long distances from markets, ports, railways, or good roads, land becomes "not worth ploughing." Much of this land that is beyond the margin (in the economic sense) of arable cultivation is still capable of paying a rent under the less intensive system of grass husbandry.

2. The next question is that of the difficulty or ease of cultivation. The expenditure on grassland is not only low, but varies within comparatively narrow limits. In the case of arable fields the expenditure is not only higher but varies, with soil and climatic conditions, within far wider limits. Thus level, free-working soils situated in districts of moderately low rainfall are those which tend to be kept under arable cultivation. Great tenacity of soil, steep slopes, excessive rainfall, liability to flooding, etc., all add materially to cultivation costs and so favour the alternative of grass farming. It will be obvious that economic conditions, such as the relation of wages to prices and the possibilities of using labour-saving devices, will also have an important bearing on cultivation costs. These questions are treated in Chapter III.

3. Apart from the question of tillage costs, the conditions that constitute maximum fertility for grass and for arable crops respectively are different. The most striking difference is in the matter of moisture requirement. Grassland is covered (throughout the year) with a more or less dense herbage, whereas arable ground is unoccupied for at least a part of the year, and is only sparsely covered with vegetation for a further season. Hence the moisture requirement of grass is much the higher, with the result that grass

tends to predominate in regions of high rainfall, on the more retentive soils and, for example, on river flats where there is a supply of water from the subsoil. Again, arable crops, most of which are required to ripen, are benefited by dry weather for this process [1] and for their harvesting; whereas with grass, prolonged vegetative growth, which is favoured by continuously moist conditions, is what is wanted. This connection between moisture and cropping is very easily traced if rainfall and cultivation maps of this country be compared. Again, arable crops pass through phases, such as the seedling, the flowering, and the ripening stage, when they are liable to suffer disastrous damage from climatic agents like late or early frosts, summer hail, wind, rain, fog, or drought. These may act either directly on the plant or may produce damage by encouraging insect pests or fungoid diseases. Grass suffers relatively insignificant damage from such causes. Hence under very uncertain climates land has very little value for arable purposes and yet may be very valuable for grass.

4. The "agricultural situation" of a piece of land (*e.g.* its position in relation to other land and its accessibility to the farm buildings) may also prove a determining factor. Thus, as will be made clear below, certain advantages accrue from having both grass and arable on the particular farm. Hence in mountain grazing districts one finds small areas of land kept under arable cultivation, not because they are intrinsically suited for this purpose but only because they are less ill-adapted than surrounding areas. Within the individual farm a limited area of pasture quite close to the farm buildings is a convenience of obvious value. Apart from this the more distant or less accessible fields will tend to go to grass, while the land of easier access will tend to be kept as arable. The question of water supply to grazing stock is another point that must be borne in mind when a scheme of allocation is under consideration.

Regarding the two modes of utilizing grassland, it is obvious that wherever there is a definite winter season, where anything approaching intensive methods of stock feeding are adopted, and where there is no sufficient supply of arable-land products, part of the produce of grassland must be conserved by one means or

[1] In certain areas—*e.g.* the West of Scotland and West of Ireland—the difficulty of hay and corn harvest is partly caused by the high rainfall, but even more by the high average relative humidity of the atmosphere. The drying of crops is protracted because the air is so often almost saturated with moisture.

another. Seasons of drought, whether of regular or occasional occurrence, fall to be provided for in the same way, Mowing and conservation (hay-making, ensilage, or artificial drying) involve a considerably higher expenditure than grazing, so that the more productive of the grasslands will usually be set apart for mowing. Relative freedom from obstacles is also of importance. Apart from this, lands that are too wet to carry stock, or are unhealthy for grazing animals, will tend to be allotted to permanent meadow.

Very frequently it happens that the most profitable system for a particular farm includes both arable and grass. Apart from the question of the distribution of risks, it is often desirable that a certain quantity of stock should be permanently maintained, *e.g.* dairy, or "regular" breeding stock. And in such cases it will generally happen that pasture provides the cheapest summer food, while the winter requirements can often be most economically met by arable cropping.

In alternate (as opposed to merely mixed) husbandry there is the further important advantage that grassland accumulates nitrogen and humus, whereas tillage exhausts the soil of these very important constituents. Moreover, weight must be given to the fact that temporary grass, at least in the earlier years of its existence, is commonly much more productive than permanent grass under similar conditions. This is because, except under systems of management that are not widely practicable, less productive and nutritious plants tend to increase at the expense of the best pasture species. The broad result is that a given standard of productiveness can be maintained, under a system of alternate husbandry, with a lower expenditure in labour and manures than under a system of permanent division into arable and grass. On the other hand, land under the alternate system requires a measure of double equipment—it must be fenced and supplied with water if it is to be grazed, and for arable purposes it must have roads. Added to this is the additional expenditure for periodic reseeding with grasses, and the well-known risk of failure that attends the laying down of land to grass. The latter obstacle to alternate husbandry assumes most importance on the heavier soils, on which a suitable tilth for the smaller seeds is difficult to obtain, and in the drier areas. In reaching a decision for the one or the other system of mixed farming, the one set of considerations must be balanced against the other. If the land of

a farm is tolerably uniform in fertility and accessibility, and its soil of fairly uniform texture, and if grass is not too difficult to establish, alternate husbandry should generally be preferred. If, on the other hand, the land of a farm includes rich and poor, high and low, heavy and light, etc., or if it is difficult to lay down to a good sward, then a permanent division may be the more profitable scheme. Recent progress in the technique of pasture making, *e.g.* by the introduction of leafy and persistent strains of grasses and clovers, is tending towards the increase of alternate husbandry. Under conditions that are unsuitable for arable crops there is the possibility of breaking up and directly reseeding grassland when its productivity has declined.

CAPITAL

Farm capital includes all the equipment that is necessary to make the land productive. It is usual to draw a distinction between such forms of capital as are practically inseparable from the land—buildings, roads, drains, etc.—and such as are readily separable—implements, live stock, annual crops, etc. Obviously this distinction is not absolute, *e.g.* a wire fence is movable, but the cost of moving it may represent a considerable part of its value; a hill sheep flock is readily movable, but its value in the market may be less than its value on its native grazing. A sum spent in manuring with nitrate of soda is probably recoverable within a year, one spent on slag in perhaps three or four years, and one spent on liming perhaps not in ten years. However, the broad distinction is important, especially in countries such as Britain, where the landlord-and-tenant system prevails. Here the fixed capital is the property of the landlord, and interest on it is included in the rent, while the movable capital is furnished by the tenant. Questions regarding the quasi-permanent forms of capital are settled by custom, by covenants in leases, or by law. Thus improvements carried out by a tenant are classified under the Agriculture Act (1947) in four groups. Part I of the Third Schedule sets out improvements such as the planting of orchards, bush fruit and hops, the making of irrigation works, and the working of land; here the consent of the landlord is required in order that the tenant may have the right to compensation. Part II of the same Schedule gives a list of the improvements to which the consent of the landlord, or the approval of the Minister,

is required.[1] These include such improvements as the erection of buildings and silos; the making of roads or permanent fences; claying, marling, and drainage (other than mole drainage); land reclamation; the laying on of electric light; and the growing of herbage crops for commercial seed production. Part I of the Fourth Schedule enumerates the improvements in respect of which no consent is required—chalking, liming, application of fertilizer, mole drainage, etc. Part II of the same Schedule deals with other matters in respect of which compensation is payable to the tenant—crops or other produce grown in the last year of the tenancy; growing crops; seeds sown; cultivations, fallows, and other acts of husbandry; and the laying down of land to pasture.

Landlord's Capital.—*Buildings*, apart from dwelling-houses, comprise stables for work horses, implement sheds, storage accommodation for produce—*e.g.* corn lofts, hay sheds and straw barns, and accommodation for stock. It will be obvious that the number, size, and quality of the buildings necessary will depend, among other things, on the climate; the longer and the more severe the winter the more commodious and the more substantial must the buildings be. Hence in the north of Scotland the capital represented in buildings generally bears a very high proportion to the freehold value of the land, whereas in the south of England the capital so invested is upon average considerably less. Again, the necessary capacity of the buildings depends on the number of stock maintained during winter. This is generally greater on arable and semi-arable than on grass farms, because of the larger stock of machinery and the storage space required for crop produce. Thirdly, the accommodation required depends on the type of stock that is to be kept. Thus winter-feeding cattle and dairy cows, or pigs kept on the indoor system, require much housing, whereas sheep, out-wintering store cattle, etc., require little. Since the provision of buildings will often be outside the farmer's province, it frequently happens that he must make his system fit in with the buildings available; if, however, it is within his control he must endeavour to satisfy himself, with regard to any proposed addition or alteration, that there is a likelihood of an economic return on the outlay that would be required.

[1] The power to give or withhold consent is normally delegated to the County Agricultural Executive Committee.

The following are approximate figures indicating the amount of space (floor area) desirable under the various heads:—

Work horses	120 sq. ft. per horse.
Cart and implement sheds . .	500 sq. ft. per pair of horses and 1200 sq. ft. per tractor, or, say, 10 sq. ft. per acre of arable and meadow.
Dairy cows	65 sq. ft. per head.
Feeding cattle (covered courts) .	90 to 100 sq. ft. per head.
Half-covered yards—covered portion .	60 sq. ft. per head.
Root sheds (roots 3 to 4 ft. deep) .	2 sq. yds. per ton stored.
Dutch barns, hay and straw sheds—	
Hay (unbaled)	$1\frac{3}{4}$ cwt. per cubic yard.
Straw ,, ...	1 ,, ,,
Unthreshed corn	2 ,, ,,

Apart from the question of the amount of available accommodation, which influences the stock-carrying capacity of the farm, its arrangement from the point of view of economy of labour has a large importance. The chief points are connected with the handling of the bulkier materials, such as roots, straw, hay, and dung. With ideal buildings, and with all materials delivered to his hand, a man can attend eighty or ninety head of fattening cattle while under the worst conditions the number may be as low as thirty. The position of the buildings is also a point of importance. This, where the land is of uniform quality, should be as central as possible. In other cases the ideal position is nearer to the most fertile and most intensively worked portions. Access to public roads is also an important consideration as affecting the most convenient point. Access to the various storage buildings, stockyards, cowshed, etc., should be so arranged that there will be a minimum of interference between vehicles and live stock. On very large holdings subsidiary homesteads may be desirable.

Fencing of subdivisions of the farm becomes necessary wherever grazing and cropping are carried on together; also, on purely grazing land, fences are essential if the grazing animals are to be properly controlled and the herbage is to be fully utilised. In general the more intensive the system of grazing the smaller must be the individual enclosures. On the poorer types of grassland, *e.g.* hill grazings, the erection of fences will often not be justified economically. Fences may be either temporary or permanent. Hurdles, sheep netting, electrically charged wires, and various forms of folds are used in certain cases in preference to fixed fences.

The cost of fencing per acre (where the shape of field is constant)

varies inversely as the square root of the area; *e.g.* if one field is four times the size of another, the length of fence required will be only twice as great, or half as much per acre. Fencing imposes a considerable burden on the land. For example, if we erect a substantial wire fence for 4s. per yd., the outlay will amount to £8. 16s. per acre for 10-acre square fields, or to £4. 8s. per acre for 40-acre square fields. These sums will represent annual charges, including interest and upkeep, of perhaps 5s. and 2s. 6d. per acre respectively.

The number of fields in the case of farms run on a system of alternate husbandry cannot be less than the number of years in the rotation, *i.e.* a four-course farm must have at least four fields, and a seven-course farm at least seven fields. It is often necessary, in the interests of efficient management of the temporary grass-lands, and especially when several different classes of stock have to be provided for, to increase this number—say two- or three-fold. Very small subdivisions such as exist in many parts of England lead to great inconvenience in working, as well as to a very considerable loss in the total cultivable area.

Fields should be rectangular, unless natural obstacles, etc., impose some other shape; irregular shapes involve a very considerable loss of time in cultivation. For large fields (say 30 acres or more), square is generally the most convenient shape. Smaller fields should preferably be oblong, in order to give a longer furrow and so more economical working.

Roads are a necessary adjunct to the arable farm; the type necessary is dependent on the nature of the traffic they have to carry, particularly on the amount of heavy winter carting. Thus if sugar beets or potatoes are to be carted off and dung carted on, a tolerably well-built road is essential; whereas if roots, etc., are to be folded, the carting is reduced to seed, artificial manure, and such produce as cereals, and the provision of the necessary access may cost little or nothing. Where roads are required to carry heavy traffic and where there are local supplies of sand and gravel, roads or wheel-tracks of concrete should be considered as alternatives to macadamized roads. Another alternative, on certain types of soil, is the modern soil-cement road.

Drainage, either natural or artificial, is essential under British climatic conditions if the maximum returns from arable land are to be obtained. The cost of tile drainage at 1953 prices and wages varied from £40 to £80 per acre, representing an annual charge

of £2. 10s. to £5; and drainage can only be expected to be carried out if the probable increase in the annual value of the land reaches such a figure. Mole drainage, of course, provides a cheap substitute on heavy land of suitable configuration. At the time of writing (1954), State grants up to 50 per cent. of the approved costs could be obtained for all approved schemes of land drainage.

Water supply is of obvious importance. The carting of water for stock is very expensive, and a reliable supply of uncontaminated drinking water is thus an asset of great value. Open ponds which collect surface water are dangerous to the health of live stock, particularly in spreading Johne's disease among cattle. Apart from the amount and purity of the supply, the temperature of the available water is a material point on dairy farms, since on this depends the efficient cooling of the milk. Deep-well water is to be preferred, since it maintains a low temperature in summer. State assistance can now (1953) be obtained for approved water-supply schemes.

Other forms of improvement—*e.g.* clearing of forest land, removal of stones, etc.—may represent large capital sums. All the foregoing forms of capital investment must be taken into account in assessing either the freehold or the annual value of a farm. It does not follow, of course, that the value of a farm is the original value of the unimproved land plus the actual sums spent in equipment and improvement, because the actual value of an improvement may bear very little relation to its original cost. Buildings may become obsolete—*e.g.* ill-adapted to a new system of farming which is otherwise desirable—while they are still structurally sound, and stone walls or hedges, made at considerable cost, may have become impediments to mechanized tillage. The capital value of land, of course, varies with the rate of interest that can be obtained on long-term investments of other kinds. The actual method used by land valuers is, firstly, to estimate the annual rental value to a good tenant. From the gross rental is deducted any fixed outgoings (land tax, tithe redemption annuity, etc.) and also the estimated annual cost of repairs and maintenance. The capital value is then calculated as so many "years' purchase" of the net rental—*e.g.* twenty, twenty-five, or forty years' purchase according as the current rate of interest is 5, 4, or 2½ per cent. If there seems to be opportunity for making improvements that are likely to return more than the normal rate of interest, some addition will generally be made to the value so arrived at.

Tenant's Capital.—The movable capital of the farm, or tenant's capital, may be conveniently dealt with under the following heads:—

1. *Standing Capital*, corresponding to the "machinery and plant" of the manufacturer, and consisting of things which are used continuously or repeatedly for productive purposes, and are replaced only when they are obsolescent or more or less worn out, viz.:—

(*a*) Tractors and work animals.
(*b*) Permanent dead stock — *e.g.* implements, machinery, harness.
(*c*) Fixed or "regular" live stock, *e.g.* dairy herds or breeding flocks maintained at a constant level.

2. *Working or Floating Capital*, corresponding to the manufacturer's "stocks in hand or in process of manufacture," and constituting that portion of the capital that is turned over, and is continually changing its form. On an arable farm in midsummer this would be represented by growing crops, unexhausted manures, etc.; in winter by roots, hay, straw, unsold grain or potatoes, tillages, dung, fattening cattle, and so on. If we imagine the case of a farmer taking over a bare farm, the working capital would be held, at the beginning of his occupancy, in cash, and the amount required would be calculated as the sum necessary to meet all current expenses until such time as the farm was expected to become self-supporting. The chief heads under which expenditure might be required are:—

(*a*) Seeds.
(*b*) Lime, manures, and fertilizers.
(*c*) Feeding stuffs.
(*d*) Temporary stocks of animals for the utilization of surplus roots, straw, etc.
(*e*) Wages.
(*f*) Rent, rates, taxes, and insurances.
(*g*) Miscellaneous — horse-shoeing, implement repairs, veterinary attendance, expendable stores such as coal, oil, binder twine, etc.

In practice, when the tenancy of a farm changes hands, the new occupier is ordinarily required to take over from the old, at the valuation of a third party, such parts of the investment of the

former as cannot conveniently be realized otherwise. On the other hand, if an outgoing tenant has allowed the land to become foul, has failed to maintain a reasonable level of soil fertility, has neglected fences and ditches, etc., he is chargeable with the extra cost of restoring the land to a proper state of cultivation. The custom in many districts is to hand over this sum to the new tenant, who in turn binds himself to leave the farm in good condition. The valuation of the tenant right is a matter for a professional valuer, who must be acquainted not only with the law but also with the procedures and bases of valuation agreed by the professional bodies. Formerly the business was complicated by the existence of a great variety of local customs which had the force of law, but many of these complications were removed by the 1947 Act.

Farm Tractors.—Over a great part of Britain oxen were at one time largely used for farm work. In this country ox teams were gradually replaced by horses, chiefly between 1750 and 1840; but in many other countries oxen, and even cows, are still largely used. About 1850 steam tillage became possible and many people believed that steam power would largely replace horses. But the common unit of steam tackle—a pair of heavy engines drawing ploughs, etc., by cable—proved too costly and was not sufficiently adaptable to the variety of tillage operations. Moreover, steam power was unsatisfactory for farm transport. Tractors with internal combustion engines assumed some importance during 1917-18, but numbers declined again soon afterwards. Since 1930 there has been a rapid development of mechanical tillage, with a continuously growing population of tractors of various types (crawlers, heavy- and light-wheeled models, row-crop types, and small market-garden types). The rate of increase in the numbers of tractors was greatly accelerated during the war years and since. In 1939 there were about 55,000 farm tractors in England and Wales: in 1952 there were about 285,000. As the number of tractors has increased the number of horses has decreased, but the reduction in the horse population has not been so great as might have been expected, even after making allowances for the greatly increased tillage acreage since 1939. This is probably due to the tendency on many farms to retain some of the horses for doing odd jobs and for certain jobs for which they are more suitable than tractors, and as a reserve of power for peak-load periods.

The range of tractors is now considerable. At one end there are small single- or two-wheeled horticultural types and at the other very powerful tracklayers of 40 h.p. or more. The smallest of the horticultural types can be fitted with a variety of attachments, but their power is so low that they can be used only for light work such as hoeing. Slightly larger models of the same general design are suitable for ploughing and some are fitted with rotary cultivators; but the high-powered (4 to 8 h.p.) two-wheeled tractors are often difficult to handle on heavy work. The large tracklayers are usually contractors' machines, since only very large farmers can justify the capital outlay involved. It is from the tractors falling between these two extremes that the farmer makes his choice. They include the medium-powered tracklayers and the medium- and high-powered wheel tractors. Tracklayers cost more than wheel tractors of similar horsepower and their track equipment may be expensive to maintain, especially when used on sharp sandy soils. They are, therefore, only chosen when the work is too heavy or the slopes too steep for wheel tractors. Unless the amount of such types of work is sufficient to justify the purchase of a tracklayer it may be more economical to employ a contractor or, alternatively, to equip a wheel tractor with half-tracks. In the latter case the half-tracks would be replaced by wheels for the lighter work of the spring and summer. High-powered wheel tractors are useful for heavy work. The larger types of 35 to 40 h.p. are frequently incapable, because of wheel slip, of utilising their full power on normal field operations, but their weight as well as their power make them very suitable for heavy haulage and they are often used by threshing contractors. It is the medium-powered wheel tractor that has become the general-purpose tractor on British farms.

Numerous surveys have been carried out to determine the tractor time spent on various kinds of farm work, and in some cases a comparison has been made with horse time. The N.I.A.E. in 1944-45[1] found in a survey on eighteen farms ranging in size from 109 to 1000 acres and covering very diverse types of farming that carting accounted for a third to a half of all tractor and horse work. Two further interesting facts emerged from this survey. First, 72 per cent. of the carting was done by horses, and second, a half to three-quarters of horse time was spent

[1] "Farm Carting," *Agricultural Engineering Record*, Vol. I, Winter, 1945-46, p. 50.

carting compared with a quarter of tractor time. These facts emphasize that if tractors are to replace horses completely, at least some of the tractors must be suitable for transport work. As was to be expected the greatest proportion of tractor time was devoted to field work—about 66 per cent.—and 9 per cent. to stationary work. Very similar figures to these were obtained in a later survey in 1951-52 by the Department of Economics (Agricultural Economics), University of Bristol.[1] An analysis of the work done by 43 medium-powered wheel tractors on 34 medium-sized mixed farms in Devon, Cornwall, and Dorset, together with three large arable farms on chalk downs in Dorset, showed that the tractors spent 60·8, 36·8, and 2·4 per cent. of their time on field work, transport, and belt work respectively. A breakdown of the " field work " item in both of the surveys referred to above shows that ploughing and basic cultivations took up 34 to 43 per cent. of the tractors' time. Other tractor jobs included sowing of crops and artificial fertilizers, harvesting, and row-crop work. The results of these surveys show that the modern general-purpose tractor must be extremely versatile, and for it to be efficient it must have the right equipment.

Versatility is of the greatest importance on the one-tractor farm where the tractor has to be capable of efficient field work and be of a type that can run from field to metalled road without loss of time. Before the advent of the tractor pneumatic tyre a steel-wheeled tractor had to be fitted with road-bands before it could be taken on the highway. This was invariably a slow and laborious procedure. The tractor fitted with pneumatic tyres can run straight from the field on to the road; it is capable of much higher speeds on the road than a steel-wheeled tractor with road-bands; it is efficient under a wide range of soil conditions; if soil conditions are such that excessive wheel-slip occurs, the fitting of tyre girdles (which can be put on and taken off the wheels quite quickly) or of strakes (which, when not required, can be folded back into the centre of the wheel) greatly improve adhesion. These considerations show that the introduction of the pneumatic tyre has probably played a bigger part than any other single factor in making possible the substitution of tractors for horses or other draught animals on farms not only in Britain but also abroad. Transport work on some farms, and especially on market gardens,

1 " A Study of Tractor Operating Costs and Performances in the South-west of England, 1951-52," by K. G. Tyers, B.Sc.(Agric.).

can frequently be done satisfactorily with special transport vehicles or, if transport distances are long, with motor lorries. It should be remembered, however, that no economies are effected if, by providing special transport vehicles, tractors suitable for the work are left idle.

Taking the country as a whole only a small proportion of the tractor's time is spent on row-crop work, but in some areas, such as the Fens, tractors are used more widely for this type of work than in others. The introduction of tricycle-type tractors to help mechanize row-crop cultivations was influenced almost completely by American conditions and in particular by the requirements of the maize crop. Experience in this country, mainly because of the absence of any farm crop with a growth habit similar to maize, has shown that the tricycle tractor has no important advantages over the general-purpose four-wheel tractor with adjustable front and rear wheel tracks for work on row crops, and since the four-wheel tractor is frequently more easily handled on many basic cultivations and is more suitable for work on slopes than the tricycle type, it is better able to meet the requirements of farms even where there is considerable row-crop work. Again, taking the country as a whole, the proportion of the arable acreage devoted to row crops is small and is often divided between several crops grown on different row widths. The adjustment of wheel tracks can now be done quite quickly, but the frequency with which it would have to be done if it were necessary every time the tractor moved to a different crop would in the aggregate result in a considerable waste of time. Consequently attempts should be made to choose row widths for the various crops which reduce the need for track adjustment, although this may mean that some of the crops are not grown on what are considered to be the optimum row widths. Where horses are kept as well as tractors it is often convenient to use them on small acreages of crops grown in rows that do not fit in with the rows of the bulk of the crops on the farm. For the cultivation of crops in very narrow rows a tractor fitted with special narrow wheels is superior to horses because it does less damage to the plants.

Many implements, such as grass-mowers, binders, small combine harvesters, potato diggers, and harvesters, some of which were formerly driven through their land wheels, are now driven from the tractor power-take-off. Power-driven machines have many advantages, but on most tractors the speed of the power

shaft is constant at rated engine speed. Soil conditions for certain operations may be such that a low forward speed is essential, but when the tractor is operating a power-driven machine, forward speed cannot be adjusted by manipulation of the governor control lever. If it is, the mechanism of the machine is slowed down and its efficiency reduced. Because of this, modern tractors are often fitted with a wide range of gear ratios so that forward speed can be adjusted by choosing the gear to suit the conditions while maintaining rated engine speed. A very low bottom gear, giving a speed of half to one mile an hour, is necessary for operations such as mechanical potato planting and transplanting of cruciferous crops. When choosing a tractor the farmer should take into account such special needs as these.

There is no simple yard-stick for determining the number of tractors required to work a given acreage efficiently and economically. So much depends on the intensity of production, organization and management, and soil type that farm size may be of minor importance. For instance, on a heavy-land arable farm the number of days in the year when it is possible to work the land may be so much smaller than on a light-land arable farm that it requires a much larger number of tractors for a given acreage. By having adequate tractor strength full advantage can be taken of spells of suitable weather.

The numerous tractor utilization surveys that have been carried out give an indication of the tractor strength farmers have found by experience to be adequate and also of the degree of efficiency with which the tractors are used. An N.I.A.E. survey of 144 tractors on sixty farms, ranging in size from 50 to over 1000 acres and distributed throughout the country to give a representative sample of the main types of farming, showed that the average farm tractor serves about 120 arable acres and works for about 1000 hours a year spread over 160 working days. Horses were also used on the farms, there being about one horse to every 41 arable acres. The number of arable acres worked per tractor increased with the size of the farm. It varied from 44 acres on the one-tractor farm of less than 100 acres to 165 acres on the large farm of over 800 acres with several tractors. Similarly the number of hours worked by each tractor during the year increased from 532 on the small farm to 1320 on the 600 to 800 acre farm. Farms of over 800 acres showed a slight

reduction in the hours worked during the year, probably because of the use of powerful tractors with wide implements capable of high rates of working. The tractors on the one-tractor farm of less than 100 acres, or on the two-tractor farm of less than 200 acres, were not fully utilized although they were used just as intensively on the arable acreage available as the tractors on the larger farms. More recent surveys indicate that the average number of arable acres per tractor is probably less than 100, but the same general trends as those deduced from the N.I.A.E. survey are still apparent. On highly mechanized intensively cultivated market gardens the number of acres for each power unit—including two-wheel motor garden cultivators as well as four-wheel tractors—is much smaller than on farms.

The cost of tractor work is greatly influenced by the number of hours worked in the year. This is shown by the following table taken from the report of the University of Bristol, Department of Economics (Agricultural Economics), referred to earlier.

Costs per Hour according to Annual Working Hours, 1951-52

(Average of 44 medium tractors)

Hours per Year	Cost per Hour	Hours per Year	Cost per Hour
	s. d.		s. d.
200 to 400 . .	5 5¼	1000 to 1200 . .	3 2½
400 ,, 600 . .	4 0½	1200 ,, 1400 . .	2 9¼
600 ,, 800 . .	3 5½	1400 ,, 1600 . .	3 5
800 ,, 1000 . .	3 7¾	Over 1600 . . .	2 10¼

This variation, according to the number of hours worked, is explained by the fact that standing charges such as depreciation (which in this particular survey amounted to 31 per cent. of the total cost), insurance, and tax are constant, irrespective of the amount of work done. Depreciation should be related to the work done because a tractor's "life" is more fairly reckoned in total hours worked than in age; but no satisfactory method of doing this has been devised. The normal practice is to calculate depreciation at the rate approved by the Inland Revenue Authorities. In this particular survey it was 22½ per cent. of the previous year's value. The individual items contributing to the

hourly cost of the work of the 44 medium tractors are set out in the following table:—

Operating Costs

	Costs		
	Per Tractor	Per Hour	Per Cent.
	£ s. d.	s. d.	
Fuel	73 4 3	1 10	52·4
Lubricants	7 5 4	0 2	4·7
Total . .	80 9 7	2 0	57·1
Repairs	12 9 5	0 3¾	8·3
Servicing	3 8 9	0 1	2·4
Insurance and Tax . .	2 17 3	0 0½	1·2
Depreciation . . .	43 19 2	1 1	31·0
Total Costs .	143 4 2	3 6¼	100·0

The very wide variation in operating costs that can occur is shown by the statement in the report: "The individual cost figures for 'medium' tractors varied from £65. 4s. 6d. to £295. 11s. 7d. per annum and from 1s. 10d. to 9s. 4d. an hour." It has already been noted how the number of hours worked affect the hourly cost. A further factor is the age of the tractor, through influence of age on the charge for depreciation.

Field Implements.—To keep down the cost per acre of tractor operations it is essential to have implements that are capable of loading the tractor to as near to full capacity as is possible. Converted horse implements which were in the past frequently used with tractors were not always suitable because they were seldom strong enough to withstand tractor haulage and because they did not provide an adequate load. Wide tractor implements are usually required to give a sufficient load, although it is sometimes possible to compensate for a narrow implement by travelling at a higher speed. There is, however, a limit to the speed at which certain cultivations can be done and an alternative arrangement is to do two cultivations at once by using narrow implements in tandem—for example, seed harrows behind a corn drill or harrows behind a roller. There are other operations, such as the hoeing of root crops, that make very light work and cannot provide an adequate load for a medium-powered tractor;

neither can they be performed at high speeds. Such are still often done with horses.

Increasing the width of an implement does not necessarily give a proportionately greater rate of working. In an N.I.A.E. survey [1] the average rates of ploughing in acres per hour per furrow for one-, two-, three-, four-, and five-furrow ploughs were 0·29, 0·22, 0·16, 0·15, and 0·16. The significance of these figures, especially in so far as a medium-powered wheel tractor is concerned, is the difference in output per furrow between the two- and three-furrow ploughs. The three-furrow plough had a rate of working only 9 per cent. higher than the two-furrow, whereas an increase nearer to 50 per cent. might have been expected. In practice a medium-powered tractor with a three-furrow plough has frequently to work in bottom gear, whereas with a two-furrow plough it can be used in second gear almost all the time. Tractors fitted with pneumatic tyres operate more efficiently the higher the forward speed, so that it is preferable to provide them with ploughs that they can handle in second gear. Generally this means a two-furrow plough, but there are types of soil on which it may be a three-furrow. Another fact brought out by the survey is that rate of ploughing is not proportional to the power available. Wheel tractors of over 35 belt horse-power ploughed 0·53 acre an hour compared with 0·47 acre an hour by tractors of less than 20 b.h.p. Although there may be a tendency for the more powerful tractors to be used on the heavier land, the more probable explanation of the small difference between the rates of ploughing quoted is, as already mentioned, the inability of a high-powered wheel tractor to use the power available as drawbar pull.

The equipment necessary to work a farm is determined by the type of farming and the size of farm. However, there is no close relationship between the size of farm and the amount of equipment. It may not always be advisable for a farmer to purchase all the machines and tools that he could conveniently use. Certain operations such as very deep ploughing, subsoiling, mole draining, spraying, and lime spreading that are done only occasionally require special equipment and sometimes very powerful tractors. It is more economical to leave such work to contractors.

The number of ploughs is matched with the tractors available. Except possibly where an old tractor is kept for odd jobs or for

[1] "Operation Rates for Basic Cultivations," *Agricultural Engineering Record*, Vol. I, Winter, 1946-47, p. 162.

driving barn machinery, there is at least one plough for each tractor. The tractor on the one-tractor farm and a proportion of the tractors on larger farms may have two ploughs, one for deep and the other for shallow work. Alternatively there may be two sets of interchangeable bodies for the one implement. The number of basic cultivating implements, such as tined cultivators, disc harrows, various types of tined harrows, rollers, etc., is determined by the amount and type of work to be done. This is also true of planting, fertilizing, and harvesting machinery. The equipment for a one-tractor farm generally includes, in addition to one or two ploughs, a cultivator, a tandem disc harrow, a set of light and a set of heavy harrows, a wide roller, and probably a spring-toothed or a pitch-pole harrow. Depending on the type of farm there may also be a tool-bar with row-crop attachments, a combine drill, a grass-mower, a combine harvester, and a pick-up baler. Generally each wheel tractor has a trailer.

It is impossible to say, in general, how many acres provide a full year's work for any given machine or when duplication of machinery is justified. Much depends on the farming system, the organization and management, and the situation of the farm. The table on page 830, compiled from a report on a Yorkshire survey,[1] is given to illustrate the effect of farming system and farm size on the numbers and types of some of the machines and implements being used. It is necessary to indicate the types of farms included in the survey, with details of cropping and stocking. The types of farms were :—

Cash Roots Type.—Farms deriving the main part of their income from such cash root crops as potatoes and sugar-beet.

Small Cash Roots Type.—Farms specializing on cash root crops as the main enterprise, but many with a strong dairying side as well.

Light Land Mixed Type.—Devoted to general mixed arable farming.

Mixed Milk Type.—Farms with milk as the main source of income, but with substantial income from arable crops.

Wold Type.—Farms deriving their main income from cereal crops.

[1] "A Study of Farm Machinery found in Different Farming Systems in Yorkshire, 1950," *Farmers' Report*, No. 103. Department of Agriculture: Economics Section, University of Leeds.

Heavy Land Arable Type.—With corn sales the main source of income, but in some cases with an important dairy enterprise.

Cropping and Stocking per 100 *Acres of the Six Farming Types*

Crops and Stock	Type of Farm and Average Size—Acres					
	Cash Roots 260	Small Cash Roots 55	Light Land, Mixed 220	Mixed Milk 155	Wold 385	Heavy Land, Arable 295
Corn	38	37	37	44	49	49
Potatoes	13	12	6	3	2	2
Sugar-beet	8	8	3	–	–	–
Seeds mown	8	7	7	9	6	8
Seeds grazed	8	2	9	7	18	10
Other crops	9	9	8	7	13	7
Total arable	84	75	70	70	88	76
Meadow	2	4	3	4	..	3
Pasture	14	21	27	26	12	21
Total acreage	100	100	100	100	100	100
Number of cows and bulls	2	11	3	12	2	3

On the question of the provision of barn machinery it is again difficult to lay down principles of general application. On the larger arable and mixed farms (with two or three hundred acres or more under arable crops annually) it will generally be found profitable to instal a complete equipment consisting of a 20 to 25 h.p. oil engine (or electric motor or tractor), power hay-chaffer, and power bruiser and grinder or hammer mill. Other machines that may or may not be worth installing, according to circumstances, are: power root-pulper and straw or hay-baling press. On small farms, apart from threshing equipment, most of these can be replaced by hand machines. Threshers of small type are fairly common in the north, while in the south the usual practice is to hire a portable thresher. The work may often be more cheaply done on the latter plan, but in the wetter districts threshing out of doors and in large batches is somewhat wasteful of straw; and on cattle farms, where straw is valuable, a slight additional threshing cost may be justified.

Other standard equipment comprises a winnowing machine, weighing machine, ladders, sacks, stack and wagon covers, ropes,

Acreages of Crops for which First and Additional Tools are Bought

Equipment	Type of Farm					
	Cash Roots	Small Cash Roots	Light Land Mixed	Mixed Milk	Wold	Heavy Land Arable
Corn drill, Root drill, Tillage drill	All	...	All	100	100	150
Combine drill	200*	...	...	...	...	...
2nd tillage drill	200*	...	...	...	400	...
1st binder	All	20	All	All	All	All
2nd ,,	100	...	...	100	150	200
3rd ,,	...	...	...	...	300	...
Combine	200	...	...	...	...	300
Grain dryer	250	...	...	...	...	...
Pick-up baler	250	...	...	...	...	...
Potato spinner	All	5	5	5	10	5
,, harvester	50	...	...	...	...	...
Hand sorter	...	5	5	5	...	...
1st power sorter	All	...	15	...	15	...
2nd ,, ,,	50	...	...	...	...	...
Sugar-beet plough	All	5	5	...	...	...
Separate topper and lifter	20	...	...	...	...	...
Complete harvester	50	...	...	...	...	...

* Either a combine drill or a second tillage drill is bought for more than 200 acres of arable land.

"All" in the above table signifies that all the farms growing that particular crop have a machine irrespective of the acreage of the crop.

etc. Additional equipment is required for the various classes of stock: for sheep-feeding a supply of netting or hurdles, troughs, corn bins, hay racks, and root cutter; for pigs, either self-feeders or food-steaming plant may be necessary; and for the dairy, milking machine, churns, cooler, separator, sterilizer, etc., according to the method of disposal of the milk. A milking machine is now almost a normal piece of equipment where the number of cows in milk exceeds twenty. The installation of a milking machine in herds of thirty to fifty head may cost from £4. 10s. to £5 per cow.

In the Yorkshire survey a record was also made of the total farm equipment on the farms, and the following table gives the

capital investment per acre according to size of farm and farming system, assuming that all the equipment was bought new in 1950.

Estimated Capital Investment on Mechanical Equipment—£ per Acre

Farm Size (Acres)	Type of Farm				
	Cash Roots	Light Land Mixed	Mixed Milk	Wold	Heavy Land Arable
	£	£	£	£	£
100 . .	29	23	16	17	16
200 . .	18	12	12	12	12
300 . .	15	11	11	11	11
400 . .	13	8	...	8	8
500 . .	11	...	...	8	8
600 . .	11	...	...	7	7
700 . .	13	...	...	6	7

"Small Cash Roots" farms, omitted from the table because of their small size, had a capital investment for machinery ranging from £400 to £1,700. The figures in the table are higher than they would be in practice because it is very exceptional for a farm to be equipped with new machinery all round in one year. Also, when setting-up in a farm it is usual to buy a certain amount of second-hand machinery.

There are two noteworthy features in the table: (1) The effect of the farming system on capital investment. This effect could be due to one system being more profitable than another and in consequence more capital being available for the purchase of machinery, but it is more likely to be due to the need for additional machinery for the cultivation of root crops. (2) The decrease in the capital invested per acre as the size of farm increased. This is one of the most important features of farm mechanization and illustrates the fact that small farms are necessarily at a disadvantage compared with large ones. The small man finds that he must purchase certain implements without the prospect of being able to use them to their full capacity; or that others, desirable in themselves, would not repay their cost. One of the greatest problems in farm mechanization to-day is how to reduce the cost of mechanization on the small farm. There is a limit to which machines can be reduced in size: a plough cannot have less than one body, and for a given class of work, say deep ploughing, the body has to be the same size for all

sizes of farm. It is very improbable that the solution of the problem is along the line of reducing the size of the individual machines. More promising lines of approach are the co-operative purchase and use of full-size machines by groups of small farmers, and the employment of contractors, particularly for work that is not of a seasonal character. Co-operative ownership and use of machinery is practised on a small scale, and although it is satisfactory for such jobs as ploughing and general cultivating there are great difficulties when it is extended to include machinery for the harvesting of corn crops, which cannot be left standing without serious risks of losses once they are fit for harvest. The harvesting of farm root crops on the other hand can be spread over a long period and is therefore more suitable for co-operatively owned machinery than the harvesting of corn crops.

Live Stock.[1]—The live-stock carrying capacity of a farm is based mainly on the amount of home-grown food available and the quantity of purchased feeding stuffs that is obtainable or that may be profitably used. Other considerations that may arise are the amount of housing and sometimes the quantity of litter available.

The requirements of the *work horses* form a first charge on the supplies of food, litter, and housing. The annual requirements of a farm horse of good size (1500 lb.) on an ordinary mixed farm might be calculated, in terms of starch equivalents, somewhat as follows:—

	Lb. S.E.
Maintenance, 365 days at 5½ lb. starch equivalent per day	=2000
Work, say 200 working days of nine hours = 1800 hours at 1½ lb. starch equivalent per hour . . .	=2700
Total .	=4700

These requirements might be met by:—

	Lb. S.E.
2 tons oats at 60 per cent. starch equivalent . .	=2700
1½ ,, hay at 30 per cent. starch equivalent . .	=1000
½ ton oat straw at 20 per cent. starch equivalent .	= 220
¾ acre pasture or, say, 3½ tons grass at 11·5 per cent. starch equivalent	= 900
Total .	=4820

The litter requirement is less definite, but may be put at between 30 cwt. and 2 tons of wheat straw or its equivalent annually. Hence, on the ordinary sort of mixed farm, the requirements of

[1] Permanent stocks and temporary or flying stocks are, as a matter of convenience, dealt with together.

a work horse might be met by 2 acres of oats (grain), 1 acre hay, $\frac{1}{3}$ acre oat straw, 1 acre wheat straw, and $\frac{2}{3}$ acre pasture.[1]

Live-stock production can, of course, be carried on wholly with purchased feeding stuffs and litter, land being required only for buildings, with perhaps a small open space for exercise. Up till about 1870, milk for the larger city markets was largely produced in town dairies because, until that time, long-distance transport of liquid milk was impracticable. The cattle were fed partly on by-products such as milling offals and brewers' grains, partly on greenstuff, roots, hay, etc., brought from the surrounding countryside, and partly on ordinary market concentrates. The usual practice was to buy mature cows in full milk and to sell them for slaughter as they dried off. This system still survives in a few cities. A not very different system is found in Lancashire, the West Riding of Yorkshire—and elsewhere to a more limited degree—where many farms are stocked far beyond their normal carrying capacity so that large quantities of hay and other bulky foods, as well as of concentrates, have to be purchased. Such holdings operate very successfully when imported feeding stuffs are cheap, particularly because the producer frequently has an opportunity to retail his product. Under other circumstances, such as have prevailed since 1940, the system has encountered great difficulty.

The same observations apply to intensive pig keeping and poultry farming, where the business is simply that of converting purchased feeding stuffs into live-stock products. Leaving aside cases such as the above, the live-stock enterprises of the farm, both in their nature and their scale, should be adjusted to the acreage of the farm and the productive capacity of the land.

Apart from work horses, the live stock of the farm may be regarded from many different points of view. At the one extreme we have farms whose whole produce is marketed in the form of live-stock products—either animals themselves or, *e.g.* milk or wool. Here the object will generally be to maintain as much stock as the farm can conveniently carry. At the other extreme we find farmers whose main income is derived from the sale of crop

[1] Where, as is often now the case, the bulk of the heavy work is done by tractor power, the number of working days per annum is usually less than is here assumed, the expenditure of energy is less, and a relatively light type of horse may be more suitable than the heavy draft type to which this calculation applies. In such cases the food consumption may be about a quarter or one-third less than is indicated.

products such as grain and potatoes. Here the function of the live stock is to convert the by-products of the farm into marketable form, and to assist, by their manure, in the maintenance of the fertility of the land. In such cases the live stock will be reduced to the minimum consistent with the objects in view. This point is further dealt with in the succeeding chapter, but obviously the question whether the live stock constitutes the primary or only a secondary group of enterprises will affect our calculations of stock-carrying capacity.

Summer Stock.—A convenient method of calculating stock for pasture is to reduce the various classes of grazing stock to a common basis. A suitable unit is the food requirement of a dairy cow of average size ($10\frac{1}{2}$ cwt.) yielding 2 gals. of milk daily. Throughout the greater part of the grazing season such an animal will do quite well on pasture of ordinary quality without any additional feeding and may be reckoned to require a ration of 12 lb. starch equivalent per day. In the table (p. 836) the daily food requirements of various classes of stock are set down; an assumption is made regarding the amount of starch equivalent fed in the form of concentrates, the difference giving the amount of starch equivalent that would necessarily be derived from grass. In the last column is given a number or fraction representing the pasture units to be allotted to each animal of the various types.

The value of pasture, of course, varies within wide limits, both as to the weight of grass produced and its feeding value. First-class British pastures, however, leaving out a limited number of exceptionally rich ones, may produce about 8 tons of green grass per acre during the season, with a starch equivalent of about 12—say nearly 1 ton of starch equivalent, which is just equal to 12 lb. per day for a six-months' grazing season. An acre of such pasture is therefore equivalent to 1 unit in the table on page 836. Other types of pasture will carry stock in something like the following proportions:—

	Units per Acre
Finest permanent fattening pastures and first-year seeds pastures on best arable land	$= 1\frac{1}{4}$
First-class permanent pastures and first-year seeds pastures on average arable land	$= 1$
Average permanent pastures and pastures of second and subsequent years on average arable land	$= \frac{2}{3}$
Poorer lowland and average semi-upland pastures . .	$= \frac{1}{2}$
Hill pastures	$= \frac{1}{6}$ to $\frac{1}{3}$
Mountain grazings	$= \frac{1}{60}$ to $\frac{1}{6}$

The aftermath from seeds leys, cut once for hay, may be taken as representing about or slightly more than one-third of the total annual output; that from permanent grassland that has been cut

	Live Weight	Total Daily Ration (Starch Equivalent)	Concentrate Ration (Starch Equivalent)	Grass Ration (Starch Equivalent)	Pasture Units per Head
Cattle	Cwts.				
Milch cows yielding 2 gals. per day .	10½	12	...	12	1
Fattening bullocks .	10½	13½	1½	12	1
Dairy and store stock—					
6 to 12 months .	4	6	...	6	½
12 ,, 18 ,, .	6	7½	...	7½	⅝
18 ,, 24 ,, .	8	9	...	9	¾
Cattle for early fattening—					
6 to 12 months .	5	7½	...	7½	⅝
12 ,, 18 ,, .	7	8½	...	8½	⅔
18 ,, 24 ,, .	9	10	...	10	⅚
Sheep	Lb.				
Breeding ewes, large, with twin fattening lambs . . .	200	5	1	4	⅓
Do. with single fattening lambs .	...	3¾	¾	3	¼
Do. with twin store lambs . . .	...	4½	½	4	⅓
Do. with single store lambs . . .	...	3¼	¼	3	¼
Breeding ewes, small, with twin lambs .	120	3¾	¾	3	¼
Do. with single lambs	...	3	½	2½	⅕
Yearling sheep—					
Fattening . .	100	1⅗	⅖	1⅕	1/10
Store . . .	100	1⅕	...	1⅕	1/10
Fattening weaned lambs . .	80	1½	3/10	1⅕	1/10
Horses					
Draft mare (and foal)	1500	15	...	15	1¼
Yearlings . .	700	8	...	8	⅔
Two-year-olds . .	1000	10	...	10	⅚

for hay will usually represent from a fourth to a third of the total output, depending on the time of cutting. In the pre-war period (1936-38) the area of lowland pasture per live-stock unit was about 1·5 acres, in addition to 0·7 acres of hay aftermath, making the equivalent of about 1·7 acres of full-season grazing. This rate of

stocking was certainly below the optimum. In 1946 the corresponding figures were 1·2 acres of pasture and 0·55 acres of aftermath, making the equivalent of about 1·4 acres of full-season grazing per unit. This represented, despite the substitution of temporary leys for a considerable proportion of permanent pasture, something rather above the optimum. The optimum rate of stocking, under present conditions, would probably give an average figure of ¾ unit per acre, *i.e.* the equivalent of 1⅓ acres per cow. This again, on average, would imply about 2 acres of grassland—viz. 1⅓ acres of full-season pasture and the aftermath from ⅔ acre of hay.

Carrying capacity can of course be raised above the ordinary level by the use of nitrogen fertilizers and the adoption of a system of rotational grazing. It depends, too, on the proportions of the various classes of stock placed upon it. It is least when the stock is exclusively sheep or horses, and is probably greatest when the stock comprises a large proportion each of sheep and store cattle with a few horses. Stocking must further depend on the amount of winter grazing that is wanted; if a considerable amount of autumn growth is to be left as wintering, the pasture must not be fully stocked for the latter part of the summer season.

The following calculation shows the application of the foregoing data.

A mixed farm of fair fertility provides 20 acres first-year seeds pasture, 40 acres second and third-year seeds pasture, and 80 acres secondary permanent pasture. The number of units would accordingly be:—

	Units
20 acres first-year seeds	= 20
120 ,, second-year and permanent pasture . .	= 80
Total .	= 100

The stock carried might be:—

	Units
3 work horses, at ⅔ unit	= 2·0
30 dairy cows	= 30·0
8 heifers, six to twelve months, at ½ unit . . .	= 4·0
8 ,, twelve to eighteen months, at ⅗ unit . .	= 4·8
8 ,, eighteen to twenty-four months, at ¾ unit .	= 6·0
150 large breeding ewes—	
80 with single lambs, at ¼ unit	= 20·0
70 ,, twin lambs, at ⅓ unit	= 23·3
50 yearling ewes, at $\frac{1}{10}$ unit	= 5·0
Total .	= 95·1

It will generally be wise to adjust the permanent stock of the farm at, say, 10 per cent. below the theoretical carrying capacity, otherwise in seasons of drought the farmer will be faced with the alternative of selling stock in a bad market or of purchasing large quantities of expensive concentrates. The desirable margin of safety is higher in the drier districts of the south-east than in the north and west. In favourable seasons the surplus grass may be ensiled, otherwise the pastures should be topped by the mower to prevent the plants running to seed.

Under very intensive systems of pasture management, with rotational grazing and heavy nitrogenous as well as other manuring, the carrying capacity of the middle grades of pasture in regions of ample rainfall can be increased by some 50 to 100 per cent. The same relative increase cannot be secured on first-class pastures; on the poorest classes—*e.g.* mountain grazings—the response would not be commensurate with the cost of the intensive treatment.

The stock-carrying capacity of soiling and forage crops may be calculated in much the same manner. Yields per acre may vary from 6 to 15 tons or more in the case of crops that occupy the ground for a full growing season; 8 to 10 tons is an ordinary yield of the usual mixtures grown for soiling, *e.g.* mixtures of oats, beans, peas, and vetches; rye-grass and clover mixtures when cut twice will give comparable yields. Catch-crops naturally yield less, depending on the length of time that they occupy the ground. The starch equivalent of greenstuff varies from 8 to 12 or 13 per 100 lb. Under suitable conditions for arable forage crops the carrying capacity per acre may be increased by 50 per cent. or more by substituting soiling and forage crops for pasture. This, however, is frequently insufficient to meet the extra charges involved; hence, under a wide range of conditions, intensification of pasture management is to be preferred to soilage of arable crops.

Winter Stock.—For winter stocking, general rules cannot be laid down because the requirements of different classes of animals are not even roughly comparable. The following facts may, however, be usefully stated.

Litter.—After deduction of the quantity necessary for thatch, covering clamps, littering horses, etc., the wheat and a good deal of the barley straw produced will normally be used as litter for housed cattle or pigs. The allotment may vary within wide limits. Where straw is scarce, and regarded as a commodity of considerable value—*e.g.* on semi-arable dairy farms or north-country

cattle-feeding farms—7 lb. per head per day, for full-sized cattle in stalls, is regarded as ample. In such cases, however, there is considerable wastage of liquid manure and of nitrogen. For cattle in covered courts, a daily allowance of 14 to 16 lb. per head (varying somewhat according to the quantity of roots fed), will ensure the animals a comfortable bed and the production of the best quality of farmyard manure, but is insufficient completely to prevent loss of nitrogen. Where the cattle are running in partially open yards, and where the object is rather to tread down a maximum quantity of straw into manure, 20 to 30 lb. per head may be allowed and dung of still fair quality be produced. The allowance for young stock kept indoors may be reckoned at between 1 and 2 lb. per 100 lb. live weight per day. The allowance for pigs may be calculated on the same basis, though the Scandinavian type of house, with its dunging passage, makes possible a considerable saving.

Fodder Straws.—The utilization as fodder of large quantities of cereal straw can be attained practically only with cattle. A limited amount may be fed to sheep, chaffed and mixed with grain, and horses may consume quantities in periods when work is light. On cattle-feeding and dairying farms the whole of the available oat straw is generally used as fodder if there is sufficient other material to serve as litter. Barley straw is used as fodder in districts where oats are not a satisfactory crop. For cattle on full production rations the maximum daily ration of straw will be about 12 to 14 lb. per 1000 lb. live weight. A larger proportion makes the ration too bulky in proportion to its energy value. Cattle being kept at little over maintenance level—*e.g.* dry cows—may consume up to 20 lb. per 1000 lb. live weight per day. Straw is, of course, unnecessary if other roughage, such as hay, is available and can be used economically. Where there is a possibility of selling straw this method of disposal should be considered; in normal times, however, the market is a very limited one. If farmyard manure can be bought in exchange, the whole of the straw may be so disposed of, but where this is not possible the proportion to be sold must be decided according to the nature of the soil of the farm, especially with regard to its humus-content. Thus, black fen soils require little farmyard manure, and the bulk of the straw may be sold. At the other extreme, light soils in the drier districts decline in fertility when farmyard manure is withheld, and the selling of straw is generally to be avoided altogether. The extent to which straw must be converted into

dung depends also on the kind of crops cultivated. Cereals succeed fairly well, even over long periods, with artificials alone, whereas mangolds, potatoes, sugar-beet, and many market-garden crops are much more dependent on organic manure.

Hay, since it is a primary product and not a by-product, must be regarded quite differently from straw; that is to say, no more need be produced than can be profitably used. For many purposes straw can be used as a substitute for hay, and hence on grain farms the growing of hay for home consumption is reduced to a minimum. Hay, however, has an energy value that is from 50 to 100 per cent. higher than that of straw, and its content of protein is from three to ten times as high.

Hay may be regarded as indispensable for horses on regular work, the annual allowance per head varying from 25 to 30 cwt., according to the type of horse used and the distribution and amount of the work to be done. For young horses in winter a certain amount is generally necessary, 5 to 10 cwt. per head representing their requirement where they have a good range of winter pasture.

For cattle up to one year old, hay will generally form part of the winter ration, and the minimum allowance may be put at about 1 per cent. of the live weight per day. Sheep fattening or wintering on roots generally receive hay at the rate of ½ to 1 lb. per 100 lb. live weight daily; to grass-wintering sheep and cattle, hay may be supplied regularly, or only during spells of severe weather.

At the other extreme, *e.g.* on grassland dairy farms, hay forms the basis of the winter ration, and may be fed to cattle at the rate of fully 2 per cent. of the live weight daily.

Roots, having a high energy value in relation to their dry-matter content, and being succulent and very palatable, form a satisfactory complement to straw in the feeding of all classes of cattle. Hence if the available fodder consists mainly of straw, and if concentrates are to be used only in moderate amounts, roots will generally have to be given in considerable quantities if a full production ration is required. The maximum root ration for growing and fattening cattle may be reckoned at about 8 per cent. of the live weight daily. At this rate an average bullock would consume 7 to 8 tons, or somewhat under ½ acre of an average crop, in a six months' feeding period. For dairy cows about three-fourths of this quantity should be regarded as the upper limit, the energy requirement of the ration being made up in

other ways. Owing to the high labour requirement of the root crop and the rise in wages in relation to agricultural prices, the tendency in recent years has been to reduce root rations far below these figures. The economic ration in particular cases will, of course, depend on the ease or difficulty of growing the crop. Where hay is fed in place of straw the root ration may be reduced to any extent that may be desired, or eliminated entirely.

Sheep may receive relatively more roots than cattle—up to 15 per cent. of the live weight daily for full production, and, even in maintenance and low-production rations, roots usually take a more prominent place. It is to be noted that the cost of the crop to sheep is less than to cattle, since normally sheep consume a considerable proportion of their roots in folds, and the costly business of lifting and carting is avoided.

Fattening and breeding hoggets of the larger lowland breeds may be given 1 cwt. per week, allowing for a certain amount of wastage, or 1 ton in a winter feeding period of five months. Breeding ewes of the larger lowland types will require about the same quantity, but much depends on the date of lambing and on the amount of pasturage and other food available.

Work horses may receive up to 20 lb. of roots per day, and young horses, in proportion to their live weight, rather more. Pigs may be fed on roots in considerable quantities—up to 7 or 8 per cent. of their live weight daily, provided that the other feeding stuffs are judiciously chosen.

Kale has a higher dry-matter content than roots and is therefore normally fed in smaller quantities. Moreover, fibre constitutes a larger proportion of its dry matter, so that if it is substituted for roots on a dry-matter basis the net energy value of the ration will be reduced. The equivalent of a ration of swedes, straw, and concentrates can be obtained with a kale, straw, and concentrate combination only if the straw is somewhat reduced and the starchy concentrate—*e.g.* oats or maize meal—is increased. On dairy farms it is a common aim to provide about 40 lb. of kale per cow per day from early October till Christmas. This implies about $1\frac{1}{4}$ ton, or perhaps $\frac{1}{12}$ acre per cow.

Silage made from relatively mature crops of oats and legumes or from grass in an advanced stage of growth is best regarded as a substitute for part of the roots and hay, or for part of the roots, straw, and concentrate of a ration. It cannot be regarded as a simple substitute for roots, because it provides much less net energy value (about two-thirds) in a given quantity of dry matter.

Actually 30 lb. of average silage will replace about 50 lb. roots and 3 lb. straw.

Silage made from immature herbage—*e.g.* short grass—has a high starch equivalent and protein-content in proportion to its dry matter. It may be used as a substitute for part of the hay and part of the high-protein concentrate in the standard type of ration.

The amount of by-products, such as small potatoes, tail corn, etc., affects the carrying capacity of the farm to a minor extent. Considerable quantities of home-grown oats, barley, and beans are fed to stock, but these, when normal imports are available, are to be regarded as alternatives to purchased concentrates and thus hardly enter into stocking calculations.

The following is an example of winter stocking :—

Production of feeding stuffs and litter—	Tons
Wheat straw, 30 acres, at 35 cwt. per acre . . .	= 52
Barley ,, 10 ,, 20 ,, ,, . . .	= 10
Total litter straw .	= 62
Oat straw, 40 acres, at 25 cwt. per acre . . .	= 50
Seeds hay, 20 ,, ,, 35 ,, ,, . . .	= 35
Meadow hay, 10 acres, at 30 cwt. per acre . .	= 15
Total hay .	= 50
Roots, cabbages, kale, 30 acres, at 20 tons per acre— *Less*, say, 10 per cent. wastage	= 540

Consumption

	Mean Daily Ration per Head (Lb.)				Duration of Period	Total Consumption (Tons)			
	Litter	Oat Straw	Hay	Roots	Days	Litter	Oat Straw	Hay	Roots
Thatch, etc. .	...	...	...	...	...	4·0	...	...	...
6 work horses .	14	4	14	10	280	10·5	3·0	10·5	7
4 young horses	7	...	7	10	150	1·9	...	1·9	3
40 dairy cows .	7	8	7	40	200	25·0	28·6	25·0	143
8 heifers, 0 to 12 months .	5	...	6	30	180	3·2	...	3·9	19
8 heifers, 12 to 24 months .	7	10	4	40	180	4·5	6·4	2·6	26
200 breeding ewes . .	...	...	$\frac{1}{4}$	16	100	...	...	3·3	143
50 ewe tegs .	...	...	$\frac{1}{2}$	14	120	...	...	2·0	37
50 fattening tegs	...	...	$\frac{1}{2}$	16	120	...	...	1·3	43
15 fattening cattle . .	12	12	...	100	150	12·0	12·0	...	100
					Totals .	61·1	50·0	50·5	521

The Working or Floating Capital comprises that part which is regularly "turned over"—that is to say, realized and reinvested. The rate of turnover varies with the nature of the product. In a fresh-milk dairy, capital is invested in food and labour, and a return obtained from sales of milk practically concurrently, with the result that the amount of working capital required is negligible. In producing a spring cereal, the capital represented by seed, manure, and tillage will be laid out for a period of from six months to a year; that spent in threshing may be realized again almost at once. If grass seed be sown with the cereal crop, the capital so invested will be realized only after one or more years; and if the grass be manured with slag the return may be expected to be spread over a period of four or five years.

In practice the amount of floating capital required may be arrived at in either of two ways. Firstly, taking a farm at any season of the year, the working capital actually invested at the moment may be added to the prospective outlays that will require to be made up till such time as current receipts may be expected to equal or exceed expenditure. Thus if we enter an arable selling farm at Candlemas (2nd February), the outgoing tenant having disposed of the whole of the previous season's crop, we should pay for tillages that had been carried out, for grass seed and wheat seed already sown, and for manures and unexhausted residues. We should then proceed to estimate our probable outlays, under the heads of seeds, manures, wages, feeding stuffs, rent, insurance, and sundry maintenance charges up till, say, September or October, when sales on a considerable scale would commence, and our investment would cease to grow.

Alternatively, the total investment of floating capital may be estimated directly for the particular season of the year when it will be at its maximum. Thus in the foregoing case we should estimate the probable investment represented in the crop, manurial residues, etc., just after the completion of harvest, and the sum so obtained would represent the maximum working capital required.

It will be obvious that where the requirements of working capital vary considerably from one season to another the farmer may find it in his interest to obtain credit for part of the year rather than to have a large amount of capital lying idle at other

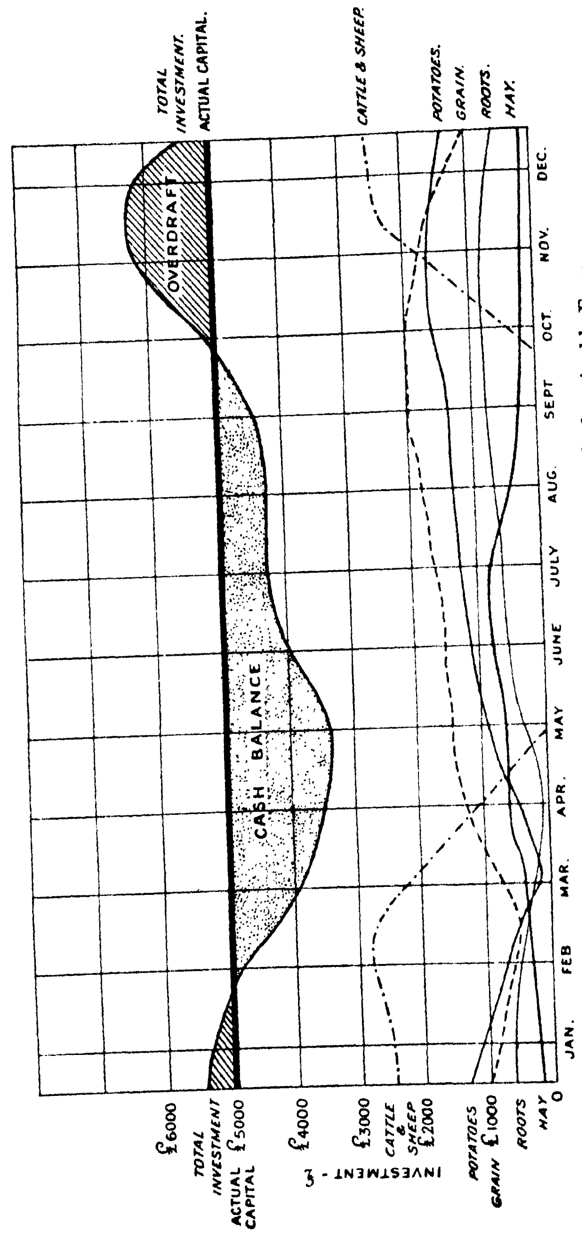

FIG. 41.—Seasonal Changes in the Floating Capital of an Arable Farm

seasons. Thus in Fig. 41 the investment in the main items of floating capital on an arable farm, over a period of a year, is shown. The farm grew 100 acres grain, 30 acres potatoes, 30 acres roots, and 30 acres hay. The live stock consisted entirely of cattle and sheep which were bought in autumn to consume the roots and straw and were sold fat between February and May. The actual working capital was £5000. In April and May, after the winter stock had been sold, the farmer had a cash balance of £1500. In November, because the winter stock had to be purchased before any considerable amount of the grain and potatoes had been realized, he had an overdraft of about the same amount. The exact amount of working capital that it would be profitable to employ on this farm, *e.g.* whether £3000, £4000, or £6000, would depend on the relationship between farming profits and bank interest. Obviously, if a farmer could make 8 per cent. on his working capital and the rate of overdraft interest were 4 per cent., it would pay him to borrow as heavily as he could.

FARM LABOUR

Labour requirements may be calculated on the basis of the acreages of crops grown and the numbers of the various classes of live stock maintained, with an allowance for "overheads," *i.e.*, work involved in the maintenance of roads, fences, and equipment generally, the wages of a bailiff (or of such part as pertains to general supervision), and any other work time that cannot be charged up to a particular enterprise. A common figure for overheads is about 15 per cent.

The following figures are derived from the investigations of farm economists as reported in the Farm Management Survey. The unit used is the man-hour, or roughly one-eighth of a man-day. There is, as would be expected, a considerable range of variation as between one farm and another—apart from that due to varying degrees of efficiency in labour organization. Thus in respect of crops, the labour expended on tillage will vary with soil type, size and shape of fields, the average distance from field gate to homestead, and the quality of farm roads. Labour expenditure per acre on harvesting or hay-making will vary with climate and the size of the crops. In the case of live stock there is considerable variation as between different systems—*e.g.* deep litter as compared with free-range poultry-keeping, or

the yard-and-parlour as compared with the cowshed system of dairying. Even when the system is essentially the same—*e.g.* yard feeding of cattle—much will depend on the layout of the buildings in relation to convenience in feeding, littering, and dung handling. The following figures are averages :—

Crops and Grass: Man Work-units per Acre

Wheat, oats, and rye—	
Binder-harvested	37
Combine-harvested	19
Barley—	
Binder-harvested	29
Combine-harvested	15
Beans and field peas	36
Potatoes	175
Turnips and swedes	120
Mangolds, sugar-beet, and fodder-beet (hand topped)	165
Kale and cabbage (carted)	110
Temporary grass—	
Pasture	3
Hay	19
Permanent grass—	
Pasture	2
Hay	17

Live Stock: Man Work-units per Head per Year

Dairy cows—	
Hand milked	200
Bucket-machine milked	140
Yard and parlour	130
In-calf heifers	20
Bulls	30
Other cattle—	
2 years and over	15
1 to 2 years	22
Under 1 year	35
Lowland sheep—over 1 year (including ewes with lambs)	6
Farm horses	75
Pigs—	
Breeding sows	36
Stores and fatteners	12
Overall (breeding, rearing, and fattening)	20

In estimating the number of regular workers required for a particular farm, the total work units are calculated from the acreages of the various crops and the numbers of the different classes of live stock, and an addition, commonly of 15 per cent., is made for overheads ; next, a deduction is made for the estimated amount of casual labour to be employed (for such tasks as potato

lifting and beet singling) to give the amount of work remaining to be done by the regular staff. The statutory hours per annum (47 hours per week for about 49 weeks) are about 2300, equivalent to 287 man-day work units. But most stockmen ordinarily put in a considerable amount of "regular" overtime, and other workers also work extra hours at busy seasons. On the other hand a small allowance must be made for sickness. Average figures seem to be about 330 man-day units for stockmen and 300 for other workers.

The following table gives the amount of labour (in man-day units per acre) actually applied on farms of different types and sizes in England and Wales during the year 1949-50. Corresponding figures for 1954 would be nearly 10 per cent. lower. The figures include work done, apart from managerial work, by the farmer himself.

Average Number of Man-day Units per Acre by Size and Type of Farm, 1949-50

(1 man-day=8 hours)

Type of Farming	Size of Farm in Acres					
	0 to 50	51 to 100	101 to 150	151 to 300	301 to 500	Over 500
	Man-day Units per Acre					
Dairying . .	11·9	9·4	8·8	9·4	7·3	7·1
Live stock with substantial dairying	8·8	7·6	5·8	5·3	4·7	3·5
Predominantly live stock . .	8·2	5·9	4·7	4·7	4·1	2·9
Live-stock fattening	...	5·6	4·5	3·8	3·1	3·9
Mixed with substantial dairying	8·2	7·3	6·5	6·3	5·9	5·3
General mixed .	10·0	8·2	6·7	6·7	6·4	5·6
Alluvial arable .	14·1	12·3	12·9	11·5	10·0	11·0
Light land arable .	8·2	8·4	7·3	7·9	7·1	6·5
Other arable .	10·6	8·8	7·3	6·3	5·4	5·2
Crops with supplementary live stock	11·8	10·6	8·2	8·2	7·4	6·7

An approximate idea of labour requirements can be made for particular farms by using the data from the table above. For instance, a farm of 180 acres falling under the description of

"mixed with substantial dairying" would typically have required 6·3 man-day units per acre in 1949-50 or 5·7 per acre in 1954. The calculated man-power requirements ($150 \times 5{\cdot}7$) are 1080 man units. The staff might thus be:—

One stockman	330 work units.
Two general workers . . .	600 " "
Casual work	50 " "
Farmer—one-third time . . .	100 " "
	1080 work units.

A rather widely variable factor, which affects requirements in the way of regular staff, is the extent to which the farmer may depend upon contractors. In areas where contract services are available it may be profitable to use these, especially for operations that require special machinery or exceptionally high-powered tractors, etc.—deep ploughing and cultivating, combine harvesting of corn; weed spraying or mechanical beet harvesting.

Minimum wage rates for prescribed hours of work are laid down by the Central Wages Boards for England and Wales and for Scotland respectively. There are separate rates for adult men, adult women, and young workers, according to age. In 1954 the weekly hours of work were forty-seven, with two weeks' holiday (in addition to general public holidays). Overtime rates are also laid down by the Wages Boards.

In 1952-53 total earnings in England and Wales (including overtime and bonus payments) bore the following relationships to the minimum wage, the latter being taken as 100.

General workers . .	101
Tractor drivers . .	104
Horsemen . . .	110
Stockmen . . .	123

Piece-work rates can be applied to certain farm operations. In general, the system has obvious advantages where the quantity of work done is readily measurable and its quality can be assessed. In some areas such operations as hedging, ditching, root singling, sugar-beet harvesting, are normally done at piece-work rates, whether by regular employees or by casual workers. On some large dairy farms the head herdsman is in fact a contractor, employing what assistance he requires and being paid on the gallonage of milk produced.

Various forms of bonus payments are in use, especially for stockmen—for instance a bonus for numbers of pigs reared in excess of six per litter, or of lambs reared in excess of a standard number per hundred ewes.

Profit-sharing schemes have been operated in some cases, but are open to the difficulty that farm profits are subject to many influences other than the efficiency and assiduity of the staff—for instance a drought or bad harvest may deprive the workers of a bonus payment that their efforts may have fully deserved. This difficulty has prevented their general adoption.

CHAPTER II

THE CHOICE OF FARM ENTERPRISES

THE first problem that arises in the organization of the farm is the selection of enterprises—the choice of the particular commodities that the farm is to be made to produce. Selection from among the various possibilities should never be arbitrary but should be based on a thorough understanding of all the conditions, natural and economic, under which the farm will have to be carried on.

The chief marketable products of British agriculture are cereal and other grains; potatoes and other vegetables; sugar-beet; fat cattle, sheep, and pigs; wool; milk, butter, and cheese; horses; eggs and table poultry; fruit, flowers, and glass-house produce. In certain cases (as, for example, that of beef) the process of production is often divided into two or three stages, so that, in fact, there are more departments in the industry than there are marketable products.

Grain.—While it is of course true that the various cereal crops have different individual requirements in regard to temperature, moisture, manure, etc., yet it is possible to lay down certain principles regarding corn-growing generally. It is to be understood that the production of grain for sale is the question immediately under discussion. The use of cereals for the production of stock food is dealt with later.

The conditions affecting the economic success of cereal cultivation are briefly as follows:—

1. *Climate.*—The operation of seeding, and more particularly that of harvesting, are most cheaply and most efficiently performed under dry conditions. Under the best conditions—such as prevail, for example, in the great wheat belt of North America—cereals may be regularly "combined" from the standing crops and put in store without a need for artificial drying. In the wetter areas of our country there is additional expense and more risk of damage at harvest. The moisture requirement of cereal crops is on the whole low, and full yields may be obtained with a rainfall of from 20 to 25 in. per annum if other conditions are suitable. A rather high amount of sunshine is beneficial both in respect of yield and

quality. Thus cereals are most profitably cultivated in the drier and sunnier districts—that is to say, in the east of Britain rather than in the west.

2. *Soil.*—Compared with other annual crops, cereals are easily satisfied as regards tilth. This arises partly from the fact that they are relatively frost-hardy and can be sown either in autumn or early in spring, when moisture is plentiful in the soil, and partly from the fact that the seeds are large, can be sown at a fair depth, and germinate readily. Cereals are therefore relatively safe crops on the more extreme types of arable soil. This fact is exemplified in the high proportion of the arable area devoted to cereals on the heavy clays of Essex and on the thin dry soils of the Chalk.

3. *Markets.*—Cereal grain has a fairly high value in relation to its weight, is non-perishable, and with modern facilities is easily and cheaply handled and transported. Hence proximity to market means relatively little in the value of the produce; on land that is near to markets the tendency will rather be to concentrate on the bulkier or more perishable commodities, so that grain-growing is left to the more remote areas. This tendency may be negatived if there is a market demand for straw as well as for grain, because straw is very costly to transport in relation to its value. The market demand for straw is, however, limited and diminishing.

4. *The Scale of Production.*—Up till the general use of the threshing machine, in the early part of the nineteenth century, there was no marked relation between the size of the enterprise and the unit cost of production of cereals. Even when mechanical threshing became normal, the needs of the small producer could be largely met by the threshing contractor with his movable equipment. Again, the early reapers were so cheap that their purchase did not impose a heavy burden on the small farm. The horse-drawn binder, a more costly piece of capital, was capable of handling some 70 acres of corn, and units of lesser size were placed at some disadvantage. The introduction of reliable medium-powered tractors, some twenty-five years ago, and of the power-take-off binder, enabled practically all the field work to be mechanized, and provided the farmer with an opportunity to make a substantial reduction in costs if his cereal acreage was of the order of 100 acres or more. This opportunity was not open to the small producer. In the thirties the high-powered tractor,

capable of pulling three or four furrows and the "combine" harvester (used in conjunction with a grain dryer), made possible a further substantial reduction in costs (and also in harvest risks) in large units. Cost accounts seem to suggest something like 150 or 200 acres as the minimum size for maximum economy in production. But the additional cost per acre, for a unit of half this size, is not very large, especially where the straw is required or can be profitably used—*e.g.* as litter or fodder for cattle.

5. *The Labour Requirements* of cereals, compared with those of other arable crops, can be brought down to a rather low figure (see p. 846). Hence high wages do not in themselves mean that cereals cannot be profitably grown. Of more consequence from the point of view of organization is the seasonal distribution of labour. On the whole this is very uneven; at the worst one may have a labour distribution such as the following, which refers to a crop of spring barley produced (A) by traditional methods, and (B) by fully mechanized methods.

	A		B	
	Man-days per Acre	Horse-days per Acre	Man-days per Acre	Tractor-days per Acre
March to April—Ploughing and seeding	2·2	4·0	1·2	1·0
August to September—Combine harvesting; baling and stacking straw	1·8	0·9	1·1	0·3
September to March—Threshing and marketing	1·6	1·1	0·2	0·1
	5·6	6·0	2·5	1·4

In an actual set of records, 37 per cent. of the total horse and tractor labour for the barley crop on a group of farms was applied during March and April, and a further 37 per cent. in August and September; the remaining 26 per cent. was spread over the remaining eight months of the year.

Since seed-time and harvest are the periods of pressure, it will be clear that the extent of cereals that can be grown will depend partly on the supply of trained labour at these times and partly on the length of the periods over which planting and harvesting can be spread. The sowing of proportions of both winter and spring varieties will ease the pressure of work at seed-time, and in districts where winter oats, winter barley, and spring wheat succeed, the harvest can likewise be spread over a longer period, because the two former mature earlier, and the last later, than the

main crops. In the extreme north and at high elevations, where there is often barely time for the crops to be sown, ripened, and harvested within the limits of the season, the growing of corn for market ceases to be an important object.

6. *Capital Investment* per acre is comparatively low. Costs of production under typical British conditions amounted to something of the order of £8 or £10 per acre in the period 1930-39. At present there is a wide range of costs owing to the varying degree of mechanization and the necessity to produce under unfavourable conditions. Costs in 1954 ranged from as little as £12 to as much as £20 per acre.

7. The necessity for *Weed Control* formerly set a rather strict limit to the frequency of cereal crops and hence to the proportion of cereals on the arable acreage as a whole. Few of the rotations in widespread use implied a higher proportion than half of the land in corn. The increasingly effective control of weeds, by means of selective weed-killers, has changed the situation in regard to what used to be the most prevalent of corn-field weeds—charlock and wild radish, poppy, corn buttercup, etc. But annual grass weeds (wild oats and slender foxtail) as well as perennials like couch and bind weed still set some limit to the frequency of cereal crops. It is possible in the south and south-east, especially where ample tractor power is available, to carry out a considerable amount of cultivation (stubble cleaning) after the grain crop has been removed from the land; hence in dry and early districts the proportion of cereals may be greater than in the wet and late areas.

8. The possibilities in regard to *the utilization of straw*, where this cannot be sold, have a rather important bearing on the profits of grain-growing. Up to a point, in relation to the production of roots especially, straw has a very considerable value, notably where other conditions tend to favour the cattle industry (dairying, rearing, or feeding). The larger the place occupied by cereals in the system, the less does the value of the straw become, until in the extreme case it is regarded as worthless and is burnt. It is, of course, true that straw may be converted into "artificial dung," and generally it will have some value for this purpose. But such is very low compared to its value in districts like Aberdeenshire, Ayrshire, or Cheshire, where large numbers of cattle are maintained and where the winter house-feeding period is long. Broadly speaking, the value of straw to the farmer

is inversely proportional to the quantity that is produced, and this fact tends to reduce the amount of variation, as between different districts, in the proportion of land under cereals.

The special requirements and preferences of wheat, barley, oats, and rye in the matter of soil and climate, and also the relative yields of grain and straw, are dealt with in Part II.

The following table illustrates the effect of soil and climatic conditions in determining the proportions of the several species of cereals. The figures are those for 1936, and war-time and

County	Mean Annual Rainfall. In.	Mean July Temperature	Mean Bright Sunshine. Hours per Day (July)	Predominant Soil. Type	Percentage of Cereal Area under				
					Wheat	Barley	Oats	Mixed Corn	Rye
Essex .	23	62	7·0	Heavy	51·0	30·5	18·0	0·4	0·1
Norfolk .	24	61	7·0	Light	34·0	49·0	16·0	0·4	0·6
East Lothian	26	58	5·5	Medium	27·3	36·3	36·2	0·1	0·05
Moray .	26	57	4·7	,,	2·2	22·5	75·0	0·2	0·1
Worcester .	30	62	6·2	Heavy	61·0	3·0	34·2	1·0	0·8
Shropshire .	30	61	6·0	Medium	38·0	14·6	44·4	2·6	0·4
Aberdeen .	30	56	5·0	,,	0·08	6·58	93·2	0·02	0·04
Cheshire .	32	60	6·0	Heavy	34·0	0·5	64·0	1·0	0·5
Stirling .	35	58	4·7	,,	17·9	1·7	79·9	0·3	0·2
Devon .	42	61	6·6	Medium	25·0	11·2	57·3	6·4	0·1
Dumfries .	42	58	5·7	,,	1·1	1·0	97·7	0·02	0·18

post-war conditions—*e.g.* the necessity to expand the acreage of wheat—have resulted in considerable changes; but it may be that the pre-war proportion will tend to become re-established.

Beans and **Peas** grown as seed crops had by 1939 become rather unimportant in Britain, occupying an area equal to about 5 per cent. of the cereal area. There was some increase during the war and post-war periods, when imported high-protein feeding stuffs were scarce; but production of pulses for animal food has again declined. On the other hand there has been an increase in the acreage of peas for human consumption.

Peas are more costly to harvest and more susceptible to damage by wet weather than are cereals, and the factors chiefly affecting their distribution are the amount of sunshine and of summer rain. Their cultivation is mainly confined to the eastern and south-eastern counties of England from the East Riding of

Yorkshire to Surrey and Sussex, Worcester being the only notable exception. The proportion of the crop is largest in Kent, Essex, Suffolk, and Lincolnshire. Pease straw (from the ripe crop) is comparable in energy value to the better cereal straws and has a protein content equal to that of average meadow hay. It is commonly used for sheep feeding. The dried haulm from picking peas has a higher feeding value, almost equal to that of hay, and the fresh material (especially that produced on farms where substantial acreages are grown for canning or freezing) makes excellent silage. The pea crop is expensive to grow and rather speculative, but the returns in good years are high. An increasing proportion of the crop consists of the so-called "garden" varieties, which are partly harvested green—either for immediate consumption or freezing or canning—and partly ripened, threshed, and either marketed as dry pulse or else processed and canned.

Beans have somewhat the same preferences in regard to climatic conditions as peas, *i.e.* they do better in the drier and sunnier districts of the east than in the wetter and duller western districts. On the other hand, the crop is much less dependent on good harvest weather, being, in fact, considerably less susceptible to damage by rain than the cereals. The result is that the northern limit of cultivation is higher than that of peas, as evidenced by the considerable areas grown in Scotland as far north as Perthshire. On the other hand, the distribution is more strictly governed by soil conditions, there being a close correlation between the clay area and the bean area in various districts. Beans can be summer-tilled more economically than cereals, though they do not form a really satisfactory fallow crop. In northern districts, where the crop is liable to be somewhat under-ripened, bean straw has a high feeding value. The feature of unreliability in yield (caused in this case by the incidence of frost damage, aphid attack, chocolate-spot disease and other factors that are not fully understood) is shared with the pea crop; the amount of variation from year to year in the average British yield is about half as large again as in the case of wheat. The bean acreage declined almost continuously during the half-century preceding 1939. It increased, as said, during the war, but has since declined again.

Potatoes.—Next to cereals, potatoes form by much the most important of our market crops.

1. *Climate.*—Potatoes thrive under a wide range of climatic conditions and, broadly speaking, their distribution is governed

to a very minor extent by the incidence of sunshine, rainfall, and temperature. This is exemplified by the acreage returns for the various counties. Among those with the highest proportion of their arable area under potatoes in 1936-39 were the Holland Division of Lincoln, the Isle of Ely, Lancashire, Fife, Dunbarton, and Shetland, while among those where the potato area was very small were Wiltshire, Berkshire, Suffolk, Roxburgh, and Aberdeen. Following the large war-time expansion of acreage, the pre-war pattern is tending to become re-established. The incidence of late and early frosts is, however, an important consideration, and freedom from the former is generally the governing factor in locating early potato areas. Another rather important point is that a cool and not too dry climate gives healthy and vigorous stocks, whereas in hot and dry regions stocks readily become affected with mosaic, leaf-roll, etc., and "run out." The demand for Scottish seed from English growers tends to the extension of the area of the crop in the north. Northern Ireland also exports a considerable tonnage of seed potatoes to England. Under warm, moist conditions the incidence of blight tends to make production more costly.

2. *Soil Conditions* have a very large influence on production costs. The best soils are deep, free-working loams; the worst are heavy clays and thin, dry, calcareous soils. Good crops may, indeed, be produced on heavy land if deep ploughing and thorough tillage are carried out; but in wet autumns the lifting of the crop is difficult and costly at the best and sometimes impossible. In low-rainfall areas, however, the earlier maturing maincrop sorts can be successfully lifted except in quite exceptionally wet years. The heaviest yields are obtained from the better fen and silt soils, the finest quality from red loams. The crop withstands a considerable degree of soil acidity and may suffer if the lime-content of the soil is high. The high incidence of common scab militates against potato production on some soils, chiefly light loams.

3. *Markets and Transport Facilities.*—The weight of marketable produce per acre is about six times as high from potatoes as from grain. Hence transport charges figure largely in the final costs, and proximity to markets, railway stations, seaports, canals, etc., has an important bearing on the position that potatoes occupy in the farming scheme. The war-time scale of fixed prices showed a range of 24s. per ton, at farm, between

the most favourably and the least favourably situated districts. The value of an average crop was consequently £8 per acre greater in the one area than in the other.

4. *Uncertainty of Returns*.—The variation in yield from year to year is in the case of potatoes rather high, being, according to the British Agricultural Statistics, about 50 per cent. greater than in the case of wheat. Moreover, potatoes do not keep, at the longest, for more than eight or nine months, so that a surplus from one harvest is of little or no use in making good a deficiency in the next. The result is that, in an uncontrolled market, prices tend to fluctuate violently from year to year, making the crop a highly speculative one. The following figures illustrate the close dependence of the price on the annual production. The prices quoted are for first-quality "Up-to-Date" (a standard maincrop variety of the time), and refer to the periods, October to May inclusive, following the respective harvests:—

Year	Total Yield (Great Britain) (Thousands of Tons)	Average Price per Ton October to May s.	d.
1906	3428	77	6
1907	2977	94	0
1908	3917	53	6
1909	3674	63	6
1910	3477	81	0
1911	3825	74	3
1912	3179	92	3
1913	3865	69	3

The main purpose of the Potato Marketing Board, which was set up in 1934 and controlled the marketing of the crop until September 1939, was to steady market prices by preventing over-supply. Each farm (except those growing less than one acre) was allotted a certain basic acreage, and the Board was empowered to exact payment for permission to increase this basic acreage. Also the Board prescribed the use of riddles of certain sizes, in order to prevent the sale, for human food, of small tubers. The size of riddle was adjusted according to the available supplies and the anticipated demand. Factories for the processing of surplus potatoes (*e.g.* for manufacturing starch or alcohol) were also set up by the Board. These measures were successful in their object of reducing price fluctuations. Under the Agriculture Act, 1947, prices of potatoes, together with those of other basic

farm products, have been guaranteed by the State at levels calculated to leave a margin of profit to the efficient producer. At the time of writing it was intended that the Potato Marketing Board would resume operation (with a measure of State control and State price-guarantee) in 1955.

5. *The Labour Requirement* of the potato crop is very high—from five to ten times that of a cereal. Other expenses, *e.g.* that of "seeding," being also high, potatoes can be most profitably cultivated on the more fertile soils, where a high gross return can be obtained. On poorer and hence lower-rented lands, a return commensurate with the expense can rarely be obtained, and the farmer must look to crops that give moderate returns at a lower cost.

The seasonal distribution of labour varies greatly according to circumstances. If conditions permit the cultivation of both early and late varieties—as, for example, in parts of Lincolnshire—the crop may give a very uniform distribution, planting extending from February till April, summer cultivation from April till July, lifting from June to November, marketing from June to May, and preparation of the land for the succeeding crops from August to April. If, however, one or other of the chief types (earlies, second earlies, or maincrops) is grown to the exclusion of the others, there will be periods of pressure at planting and harvest, especially the latter. The ordinary staff of the farm will usually be quite insufficient to harvest the crop, so that a supply of casual labour is necessary. The amount of casual labour that can be obtained often limits the acreage that can be grown. As regards the fitting-in of potatoes in the general labour scheme, planting of earlies is generally done before the sowing of spring corn and that of maincrops between the seeding of the spring cereals and the preparation of the land for roots. Early varieties are usually lifted between the hay and cereal harvests, a period when on many arable farms there is little other urgent work. The harvest of second early sorts covers the period of cereal harvest, when the regular farm staff will generally be fully occupied, so that a complete additional staff may have to be secured for the potatoes. The maincrop harvest follows the cereal harvest, and must be completed before there is a likelihood of severe frost. Hence the rate at which lifting has to proceed, and therefore the quantity of casual labour that is necessary, depend not only upon the acreage to be harvested but also on the length of time available between

cereal harvest and the onset of winter. Broadly speaking, the work is more urgent, and the supply of casual labour must be greater, in the north than in the south. The lifting and storing of mangolds and sometimes the lifting of sugar-beet is work that falls to be carried through in the same period of the year, whereas other root crops can be left in the field till later; for this reason, where the autumn is short, potatoes work into the labour scheme more satisfactorily where turnips and swedes rather than mangolds and sugar-beet are the main root crops. The invention of an efficient mechanical harvester would, of course, change the situation. At the time of writing (1955) fully satisfactory mechanical harvesters had not been produced, but it seemed that some models were within measurable distance of success under the most favourable conditions—*i.e.* on light and stone-free land in the lower-rainfall areas.

6. *Capital Requirements.*—The cost of special implements (planter, row-crop equipment, digger, and dresser) is not large in relation to an area of the order of 25 acres or more. For small acreages the capital investment per acre is high. Large-scale growers, again, may find it desirable to erect glass-houses for chitting the sets, and also stores to avoid the labour of clamping and to enable dressing to proceed in wet or frosty weather. In this case large sums are involved. The floating capital represented in the crop is of the order of £70 to £80 per acre.

7. *Manuring.* — Potatoes respond to heavy manuring — the yield is highly elastic, as we say—and in particular they give a higher average money return than any other crop from dressings of farmyard manure. Therefore the growing of potatoes is limited to a certain extent by the production of dung. Black fen land can, indeed, be quite well farmed with little dung; in some coastal areas seaweed is used as a substitute for farmyard manure and the potato area is kept up through its means. On early potato farms a similar purpose is served by feeding off catch-crops of rye-grass, rape, etc. In the silt and warp districts it is common to take the crop after a one-year clover ley, the aftermath being ploughed in as green manure, and in the moister districts temporary leys, through their contribution to the humus-content, render heavy dunging less necessary.

8. *Diseases and Pests.*—As is explained earlier (Part II, Chapter II), the acreage of potatoes that can be grown on a particular farm may be restricted by the occurrence of diseases

and pests, in particular eelworm. Eelworm control necessitates a four- or five-year rotation so that the potato acreage on infested land should not exceed 20 or 25 per cent.

9. *The By-products* of the potato crop consist of small and damaged tubers which, failing an outlet for the manufacture of starch or alcohol, can be used only for stock feeding. In small quantities they can be profitably fed to cattle, but when the quantity to be dealt with is considerable it will be more economical to feed them to pigs, for which they may supply rather more than half the energy value of the ration. Where medium-sized tubers can be sold for seed purposes the amount of non-marketable material is comparatively small, averaging perhaps under 10 per cent. Where seed-sized tubers cannot be marketed the amount may rise to more than 20 per cent.

10. *The Special Value of the Crop in Time of War* is that it produces a larger amount of human food per acre than any other except sugar-beet, and that it provides large amounts of vitamin C. The value of an average crop, in terms of calories per acre, is about twice that of an average crop of cereals.

Sugar-beet became an important crop in Britain from 1922, when the Government freed home-grown sugar from excise duty; in 1925 it was given a substantial subsidy. Factories were erected in various localities, being most numerous in the eastern counties of England. The crop is grown on contract for the factories, at a previously arranged price per ton (washed weight), varying according to the sugar-content of the roots. Seed is supplied by the factory at approximately cost price, and dried pulp, in amounts corresponding to the quantity of beet supplied, is offered back to the growers. The following are the factors chiefly concerned in the economic success of beet-growing.

1. *Climate and Soil.*—The climate in the main arable districts, from Fife to Devon, is quite favourable to beet culture. Farther north the crop does well in favoured localities. In the north the upper limit of profitable cultivation is probably about the same as that of wheat, viz., 500 to 700 ft. above sea-level. So long as the soil has good depth, and is not sour, the crop can be profitably grown on a wide range of types, from light sandy to heavy loams.

2. *Distance from Factory and Transport Facilities.*—Proximity to the factory is a very important factor. A farmer within 3 miles of the factory might be able to deliver his beet at a total transport

cost of 7s. per ton; another farmer 4 miles from a station and 50 from a factory would have costs amounting approximately to 22s. per ton. Assuming a yield of 12 tons gross per acre, the net returns would be £9 per acre higher in the first case than in the second. There is, however, an arrangement by which the factories pay a proportion of the transport costs of the more remote growers.

3. *Labour Conditions*.—The hand-labour requirement of the crop is high, and it is specially important that the operations of singling and lifting should be timeously performed. The availability of sufficient labour at the periods in question is essential. In contrast with the potato crop, the work of lifting is unsuitable for children and may be too heavy for some women workers.

4. *The Value of the By-products* (tops and pulp) varies in importance according to the system of farming. The value of tops is greater where sheep are kept, and that of pulp probably where dairy cows or winter-fattening cattle are a feature of the farm.

The capital involved is considerably lower than in the case of potatoes, the cost of production per acre, apart from transport, being about three-fifths of that of potatoes. The largest difference is in the cost of seed.

Hay.—The cultivation of hay for sale is restricted, owing to the bulky nature of the crop, to areas that are fairly close to market. In times past the chief market was for the feeding of city horses and mine ponies, and with the replacement of these by mechanically driven vehicles the demand for hay declined very markedly. There is still, however, a considerable trade between the South-east of England and the Western uplands. Demand is, however, very variable from year to year, depending upon the weather during the hay-making season in the pastoral uplands and on the severity of the winter. Apart from the question of proximity to markets, hay tends to assume the greatest importance on the heavier classes of land. This is partly because of the unsuitability of heavy soils for other market crops such as potatoes and sugar-beet, and partly by reason of the saving in cultivation costs effected by placing such land under hay. On calcareous soils, particularly in the south, clover, lucerne, and sainfoin can be profitably cultivated.

Of the minor market crops that are grown under farm or quasi-farm conditions the most important are hops, mustard, linseed, and flax; vegetables such as cabbage, cauliflower,

brussels sprouts, carrots, and onions; and roots, clover, and grasses for seed.

Hops have a very heavy labour requirement—say, from double to treble that of potatoes—and ordinarily repay very liberal manuring and very intensive treatment generally. Hop-growing is a highly specialized business, and involves a large capital expenditure in the matter of poles, kilns, etc. Yield and quality are closely dependent on soil and climatic conditions, a deep, medium or heavy loam or marl on an open well-drained subsoil, abundant sunshine, shelter from strong winds, freedom from late and early frosts, and a dry picking season being all-important. The result is that hop-growing in Britain is almost entirely restricted to two main areas, viz., Kent, Sussex, and Hampshire on the one hand, and Hereford and Worcester on the other. Even within these areas it is only in comparatively small districts that the crop occupies a large proportion of the land. The Hops Marketing Board controls the acreage of the crop and the marketing of the produce.

Brown Mustard (for seed) is a crop that can be most profitably grown on deep, fertile, rather moist soils. It requires to be harvested within very narrow limits of time and is easily damaged by bad weather, so that a dry harvest period is very important. The area required to supply market requirements is not very large—about half of 1 per cent. of the cereal area—and the crop is therefore closely restricted to a few specially suitable districts in the east of England, principally in the fen districts of Lincoln, Cambridge, and Norfolk.

Flax, in spite of a considerable amount of artificial encouragement during periods of war, does not appear to be destined to occupy any large permanent place in British agriculture. The amount of labour required in pulling, retting, etc., is rather high, so that countries where unskilled labour is cheap are able to compete with this country upon very favourable terms. The invention of mechanical pullers has done something to alter the balance. Moreover, the value of the clean fibre—often about £100 per ton—is so high as to make freight an almost negligible item in costs. The home producer, therefore, obtains little advantage from his proximity to the consuming centres. The crop has long been cultivated fairly extensively in Northern Ireland, and during both World Wars reached a considerable acreage in both England and Scotland.

Linseed—*i.e.* varieties of flax grown for seed—requires little labour (less probably than the average cereal), but here, again, the product has a high value in proportion to its bulk, and hence tends rather to be grown in districts remote from markets where suitable land is cheap, *e.g.* in Argentina. The crop is of value on "cereal-sick" land (cereal eelworm, eye-spot, etc.), but its cultivation costs are about as high as those of a cereal and the value of its produce is commonly less. It may also be sown where a cereal crop has been destroyed—*e.g.* by wheat bulb fly.

The growing of **Vegetables** as field crops is determined partly by proximity to market and partly by the occurrence of soil or climatic conditions which permit of early sowing and of regular daily harvesting. Instances are to be seen in the wide cultivation of carrots in Lindsey, the Isle of Ely, the East Riding of Yorkshire, and Norfolk; of onions and brussels sprouts in Bedfordshire, of asparagus in the Vale of Evesham, of broccoli in Cornwall, and of celery in the Fens. Such crops are all expensive to produce, and some require special knowledge and skill. In recent years, however, increasing areas of brussels sprouts, cabbage, broccoli, carrots, and green peas for canning and freezing, threshed peas for processing and also carrots have been grown on holdings that are more properly described as farms than as market gardens. The mixed farmer has the advantage over the market gardener that such crops can be used for stock feeding if it happens that they cannot profitably be sold.

The principal **Seeds** produced in Britain (apart from cereals and pulses) are clovers, roots, and grasses.

Clovers are all dependent on insects for fertilization, so that the seed yield is very closely governed by the amount of summer sunshine. They are also very susceptible to damage from wet weather at harvest. Consequently, the clover-seed industry is confined to the south-eastern half of the country from Somerset to Lincolnshire and to certain small areas in Cornwall, the Severn Valley, and Wales. Considerable quantities of clover seed are imported from New Zealand, France, Canada, etc., where climatic conditions are more favourable to production than anywhere in Britain. But the closer adaptation of the home strains to their native conditions enables English seed to command a higher price than imported, and thus gives the home grower a compensating advantage. Sainfoin seed is produced on the more highly calcareous soils in roughly the same areas as are the

clovers. So far, little success has been achieved in attempts to produce lucerne seed in commercial quantities in Britain.

Root Seeds can be grown over a somewhat wider range of climate, but give the most satisfactory results where the winter is fairly mild, the summer dry, and the soil deep and fertile. Lincolnshire, Essex, and Kent produce the main supplies.

Grass Seeds.—Up till the thirties British requirements of grass seeds were met for the most part by imported supplies. The chief exceptions were the rye-grasses—of which considerable quantities were grown in Cambridge, Ayrshire, Stirling, and the North of Ireland—and timothy, grown mainly in Stirling. With the growing demand for pedigree strains of grasses the culture of other species for seed has increased, and has spread to many other areas. Good crops are now harvested in counties as widely separated as Hereford, Hampshire, Lincolnshire, and Northumberland.

LIVE STOCK

The keeping of live stock is a feature of practically all the systems of farming that have endured in Britain over long periods of time. The exceptions are mostly apparent rather than real; for instance, "selling" farms and market gardens have commonly relied on stable or cowshed manure, though composts of straw, etc., have been used successfully in place of dung. Again green-manuring crops, such as Italian ryegrass, have in some cases been used with success in the absence of other forms of organic manure in maintaining soil structure. In other cases crop residues—straw, beet tops, etc.—have merely been ploughed in, instead of being converted into dung. Continuous cropping, with the selling or burning of straw, etc., may ultimately result in a serious deterioration of soil structure, with a consequent fall in yields. In the case of good medium loams, however, the residues from well-grown crops may provide all the humus that is required. It has already been pointed out that different crops are dependent in varying degrees on the maintenance of good soil structure; potatoes and sugar-beet, for example, are more dependent than barley and wheat. Still more dependent are certain vegetable crops such as lettuce, onions, and leeks, whose seedlings may fail to establish on poor seed-beds and whose growth is greatly influenced by soil moisture and soil air conditions.

Thus even where stock has only an indirect function its importance may yet be great. But there are many circumstances in which live stock assumes the position of the primary department —where, that is to say, cropping is arranged to supply the needs of the stock rather than *vice versa*. It may be noted that about three-quarters of the total product of British agriculture reaches the market in the form of live-stock products—milk and other dairy produce, meat (including poultry meat), eggs, wool, and hides. A majority of British farms are "mixed," *i.e.* both live stock and sale crops contribute substantial amounts to the gross income.

Sheep.—Sheep husbandry is carried on under a wide diversity of conditions and there is a correspondingly wide variety of systems, with particular breeds adapted to each. A few general statements can, however, be made. First is that, under pasture conditions, sheep should generally be kept in conjunction with cattle. One argument for mixed stocking is that it tends to reduce the incidence of parasitic diseases to which sheep are very susceptible; this argument has, indeed, lost some of its force through the introduction of much improved preventives against the more widely prevalent and troublesome parasites, but it is still true, in some degree, that "the sheep's worst enemy is another sheep." More important is the fact that cattle and sheep are, up to a point, complementary rather than competitive in the utilization of pasture—*i.e.* mixed stocking with sheep and cattle, other things being equal, gives a higher output than stocking with either alone.

Another proverb, that "the large farm is the mother of sheep husbandry," is less true than it was. The main basis for the statement was that the shepherd's calling used to be the most highly specialized in the whole field of agriculture and that the farm flock should be large enough to provide full-time employment for a fully skilled worker. But the introduction of greatly improved dipping materials, with better methods for the control of parasitic and other diseases, has considerably simplified flock management, so that a highly specialized worker is no longer essential.

The mountain breeds of sheep are extremely active and hardy, can travel far in search of food, and are highly selective in their grazing habits, so that, given sufficient range, they can utilize herbage that no other class of animals, except goats, could live

on. Mountain pastures are indeed no exception to the rule that mixed stocking is an advantage, and a small proportion of cattle helps to control the coarser types of herbage plants which tend to increase when sheep constitute the whole of the stock. At one time mountain ponies were kept for the purpose in view, but the market for these has virtually disappeared. The difficulty in achieving the optimum balance between cattle and sheep, from the point of view of maintaining the value of the herbage, is that of wintering. Even mature cattle of the hardiest breeds require considerably more hand feeding than sheep, and young cattle on typical hill and mountain farms must be housed.

On the best types of grassland, whether used for meat or milk production, the commonest practice is to stock with a large proportion of cows or of fattening cattle, as the case may be, and a small proportion of sheep. The keeping of any large number of sheep on dairy farms tends to delay the date in spring when the cattle can be turned to grass and thus adds to the cost of feeding the herd. In some areas of good grass—*e.g.* Romney Marsh—sheep form the main grazing stock, and store cattle fill the role of scavengers. A frequent deterrent to the introduction of sheep on farms, hitherto stocked with cattle alone, is the considerable cost of providing and maintaining sheep-proof fencing.

Up till about the beginning of the present century the folded flock, commonly of one or other of the Down breeds, was an all-but-universal feature of arable farms on the lighter soils, such as those of the chalks and oolite, and the sandy and light-loam areas of the Eastern Counties. The sheep were close-folded during the greater part of the year, and a complicated system of forage cropping was required to ensure a succession of food supplies. This association of sheep with corn production on light land goes back for several centuries and became widespread with the introduction of root crops and clover. The chief reasons for its decline have been the rise in wage rates—the daily change of fold involving a very high labour charge—and the increased supplies of artificial fertilizers which have provided a partial substitute for "the golden hoof." Some few pedigree flocks of the Down breeds are still run on the folding system throughout most of the year.

On mixed farms the usual function of the arable land is to keep the breeding flock during the latter part of the winter and early spring—perhaps late January until April—and to fatten the

progeny as lambs or tegs either on rape, etc., in autumn and early winter, or on roots and concentrates in later winter and spring.

A few general points remain to be noted.

On most arable farms there are supplies of by-products that can best be utilized by sheep—pickings on stubbles, sugar-beet tops, catch crops, winter grazing on cattle pastures, etc. On large farms the utilization of such by-products may well justify the keeping of a flock throughout the year.

A " flying flock " of breeding ewes is more suitable to certain conditions than a regular breeding flock. For example, draft ewes from upland flocks may be run on cattle-fattening pastures from September onwards and sold fat, with their lambs, in June-July, thus utilizing the winter " foggage " and the spring flush of grass. The absence of sheep from the land over a period of months greatly reduces the incidence of parasitic troubles. Again, the fattening of purchased lambs, on clover aftermaths, rape, or other catch crops, or on roots, is a widespread practice not only on typically mixed farms but on those where the emphasis is on cash crops.

Cattle form on the whole the most important class of farm stock. This arises partly from the variety of their useful products—beef, milk, butter, cheese, and leather—and partly from the large proportion of coarse and fibrous materials, such as straw, hay, inferior grass, etc., that may figure in their diet. It is true that pigs will convert certain classes of foods into meat much more economically than will cattle, but this applies to a limited number of materials of relatively high digestibility. It is true, also, as indicated above, that sheep may be more efficient meat producers where herbage is sparse, and that sheep, under British climatic conditions, require less labour and equipment because they do not need winter housing; but there are many farms that can be carried on without the aid of either sheep or pigs, and very few that can be run permanently without a stock of cattle.

Cattle tend to predominate under the opposite conditions to those mentioned under sheep. Thus we find cattle occupying the chief position on the heavier and richer types of grassland, where the herbage is abundant; under the wetter climatic conditions; and, as regards arable, on the heavier, the richer, and the more intensively farmed lands. There is the further important question of the type of cattle to be kept and the particular product that is to be exploited.

The production of **Milk** for direct sale is confined to districts within fairly easy reach of markets. Recent developments in the way of cooling plant, rapidity of transport, etc., have, indeed, markedly extended the zone in which market milk is produced, and the operations of the Milk Marketing Boards have tended still further to reduce the disadvantage of remoteness from consuming centres. It is still true, however, that the producers' price declines as the distance between farm and market increases. It seems unlikely that overseas supplies of fresh milk will ever become a very important market factor, but imported dried and condensed milks enter into competition with the fresh product.

In past times, when the output of milk greatly exceeded the liquid-milk consumption, there were many summer producers who manufactured butter and cheese. As consumption has risen it has become increasingly profitable to maintain a more even output throughout the year. This implies the maintenance of a fairly constant number of cows in milk and arrangements for feeding them on full production rations at all seasons of the year; which again often implies, for maximum economy, a combination of pasture for cheap summer feeding and of arable products—roots, silage, corn, and litter straw—for winter. Purely arable dairy farming can be successful only on selected types of land, notably light soils in fairly moist climates. Grassland farms can produce summer milk very cheaply, but the maintenance of a corresponding winter supply can be secured at a reasonable cost only where large quantities of good meadow hay, or of grass silage, or both, can be cheaply produced, and when concentrates can be cheaply bought. Modern developments in grassland husbandry—the extension of the grazing season and improved methods of conservation—grass drying and tripod hay-making—are, however, making it economic to maintain year-round production on mainly grass farms. In respect of the cost of concentrates suitable for dairy cattle, this country is on the whole favourably situated, since in normal times there is a large home production of by-products from wheat milling, brewing, and oil-seed extraction.

Cows, especially those of the smaller and more active breeds, are capable of quite a high measure of production on land where cattle do not readily fatten. Hence the dairy industry tends to become established on land of moderate fertility rather than in

the very best pastoral districts. The length of the grazing season is of more importance, in relation to the cost of milk production, than the quality of the herbage. The selling of whole milk gives much more rapid returns than rearing or fattening, so that the amount of floating capital required is low and its turnover rapid.

Whole-milk production is a business requiring more than the average amount of skill and close supervision; moreover, the handling and disposal of a small daily output is relatively costly. Hence milk production is not a suitable business to occupy a minor place in the farm economy. It tends rather, where it is taken up at all, to become one of the major enterprises.

Cost accounts show that a high level of efficiency in milk production is not dependent on large-scale operation. Low costs are frequently shown by producers with 10 or 12 cows. Transport costs, however, are relatively high when the daily output is small, unless the farm happens to be on or close to a collecting route.

Cheese is from five to ten times as valuable, weight for weight, as whole milk, and is, in the case of most standard varieties, practically a non-perishable commodity. The market is therefore open to world competition, and the industry tends to be carried on wherever natural conditions permit the production of milk at a cheap rate, and where land is of low value on account of its distance from markets. The natural conditions in question comprise a long, mild, and rather moist growing season, so that the cattle may be at pasture for the greater part or the whole of the lactation period, and preferably a mild winter, so that the cost of winter housing and feeding may be kept low. Cheese-making is ordinarily carried on for part of the year only—the season of cheap food. All the cattle calve down in spring, so that most of the milk may be produced during the grazing season and so that the winter ration may be as light as possible. With moderately good market facilities it is often most profitable to combine cheese-making during summer with milk-selling during winter, at which latter season the price obtainable for milk is higher. Cheese-making involves more floating capital than milk-selling, since produce is not ordinarily marketed till it has matured, being then perhaps three or four months old. The yield of cheese per gallon (10 lb.) of milk varies, according to the variety made, from about 0·8 to 1·1 lb. Farm-house cheese-making was reduced to very small volume during the war, but since the demand for liquid milk had been fully met at the time

of writing, some revival seemed possible, particularly for the choicer type of product.

Whey is a by-product whose utilization is a matter of considerable difficulty. It contains fully one-third of the net energy value of the milk and, on the basis of composition, a gallon has about the same value as a pound of cereal meal; but its perishable nature and its very high water-content reduce its usefulness where it is produced in large quantities. Limited quantities can be utilized for calf-feeding, and large quantities—up to 2 gals. per day and per 100 lb. live weight—may be fed to pigs. Pig-feeding is therefore almost a necessary complement to farm cheese production. Some part of the output of factories is concentrated by evaporation and sold as a feeding stuff, or used for the extraction of milk sugar.

The manufacture of **Butter** or the separation and sale of cream are alternatives to cheese-making. With milk of average composition the yield of butter may be taken at about 0·4 lb. per gal. as against 1 lb. per gal. for ordinary hard cheese. The low price of imported butter which ruled for many years up till 1939, together with the guaranteed price paid by the Milk Marketing Boards for liquid milk, caused a marked decline in farm-house butter-making. Dairy factories were supplied with surplus milk at a special price, and the factory output during summer was considerable. In other countries, also, butter-making has become a factory rather than a farm industry. The separation and sale of cream is now also largely a factory industry. The by-product, separated milk, has a much higher food value than whey. On the basis of its energy value and protein-content it is worth about twice as much as whey; actually, owing to its mineral-content and the high biological value of its protein, its value for many purposes is proportionately much greater than the difference its energy value and protein-content would imply. In particular, separated milk can be very advantageously used for calves, for chicks, and for pigs between one and three months old. It is one of the disadvantages of the factory system of butter-making that the cost of transporting the separated milk back to the farm is heavy in relation to its value.

It is the general view of medical authorities that the consumption of whole milk should, on nutritional grounds, be still further increased, but at the time of writing demand had ceased to rise.

Calf-rearing.—It is generally recognised that, as regards dairy stock, there is a considerable advantage to be gained by the home-rearing of a sufficient number of heifer calves for the replacement of the milking cows as these have to be disposed of. Until quite recent times it was commonly reckoned that the number of heifer calves to be retained for herd replacement should be about 25 per cent. of the number of milking cattle. But progress in the control of tuberculosis, mastitis, contagious abortion and other causes of wastage has reduced the average replacement figure to 20 per cent. or less.

Apart from this somewhat special case, calf-rearing tends to develop in districts remote from markets where the land is of moderate quality and where soil and climate are ill-suited to the production of market crops. Under intensive conditions, *i.e.* on the better types of soil and near markets, the high rental of the land and the high sale value of whole milk make calf-rearing uneconomic. Thus in Cumberland and Westmorland, cattle under one year are normally about as numerous as cows and heifers in milk, whereas in Cheshire the latter are more than four times as numerous as the former. In general, cattle-breeding is an alternative to sheep-breeding and will have the preference on the moderately fertile mixed farms, especially those of small size.

From the age of six or eight months cattle require comparatively little labour and individual care, and may be quite as successfully reared by the large farmer as by the small; otherwise the same general remarks apply to the business of rearing during the latter stages as during the former. Where arable and pastoral districts occur fairly near together there is a considerable transference of cattle from the one to the other in spring and back again in autumn.

Summer Fattening of cattle is generally carried on where highly productive and nutritious pasture, either permanent or temporary, is available. There is the alternative, it is true, of stocking such land with the largest and most productive types of dairy cows, as is done, for example, in Holland; but although the precise causes are not understood, pastures of the finest quality frequently give a relatively better return from beef than from milk. Cows will often give quite satisfactory yields on land where cattle fatten only slowly, and hence, where the area of specially rich pasture is limited, it tends to be set aside for fattening. Soiling has a limited application in summer fattening of cattle, because

it adds rather a heavy labour expense in a department where the gross returns are normally not very high. It may, however, be that the modern forage harvester will so far reduce the cost of cutting and carrying green fodder as to make the soiling system economic, and some trials on indoor feeding with grass and other forages were in progress at the time of writing. In "fly weather" cattle indoors make substantially better gains than those at pasture.

The **Winter Fattening** of cattle provides, on the whole, the most convenient method for disposal of straw and for its conversion into the best quality of farmyard manure. Risks are comparatively small, and individual care and attention are less necessary than *e.g.* with dairy cows or calves. Hence, on the large arable farm, where the main income is derived from market crops, where live stock as a whole occupies a secondary position in the farm economy, and where only a winter stock is carried, fattening cattle generally form the bulk of the live stock. Where roots are specially expensive to produce, or where they can be more profitably folded with sheep, the wintering of store cattle may be preferred to fattening. Wintering cattle can subsist very largely on straw. These conveniences have had the natural result of lowering returns from winter feeding. The price of beef shows a different seasonal variation from that of milk. On the average the highest prices for beef obtain from March till June and the lowest in September, October, and November. During the second World War and the post-war years there was a marked decline in winter fattening. But it seemed possible at the time of writing that supply and demand would result in some change in seasonal price relationships—*viz.* an increased difference between autumn and spring prices.

It is fairly generally recognized that roots and straw in certain districts have a distinctly higher fattening value than in others. In particular, the north has an advantage over the south in this respect, so that the winter-feeding industry increases in importance from the south of England to the north of Scotland.

Pigs.—It has been already pointed out that pigs have a special value in the utilization of certain by-products from other departments—notably whey in cheese dairies and unmarketable potatoes. This accounts for the fact that, up till recent times, counties like Cheshire and Wigtown on the one hand and the Holland division of Lincoln on the other, had large pig

populations. The decline of farm-house cheese-making has coincided with the fall in numbers of pigs in the dairy counties.

There is a further connection between the proportion of arable land and the ratio of pigs to other stock—due, of course, to the fact that grass forms a food complete in itself for cattle and sheep, whereas pigs, in so far as they are kept on home-produced food, require a large proportion of grain, potatoes, etc. Thus Suffolk, Essex, Cambridge, and Lincolnshire have normally a much higher pig population, in proportion to other stock, than Devon and Wales.

Climatic conditions also play a part. In exposed situations and in cold and damp climates pigs suffer more than cattle and sheep. Out-door pig-breeding requires a well-drained soil as well as a fairly sheltered situation. In very cold and exposed areas well constructed and rather expensive buildings are required. Hence, broadly speaking, the density of the pig population decreases, in Britain, from south to north. Again, proximity to sources of various industrial by-products—*e.g.* milling offals, distillery and brewery by-products—and to supplies of swill from shops, hotels, and households, is of considerable advantage. Therefore pigs tend to concentrate in certain industrial districts and in suburban areas generally.

Owing to the relatively quick rate of reproduction, the pig population of this country was, until the introduction of a bacon pigs marketing scheme, subject to rather marked fluctuations, which caused corresponding price changes. When prices were low, breeding operations tended to be unduly curtailed and the population fell considerably. This produced a rise in prices which led in turn to some over-production, followed by a fall in price. The average time covered by one of these price cycles was between three and four years, so that the common saying "two years up and two years down" was not far from the truth. A marketing scheme for bacon pigs, designed to reduce these price fluctuations, was in force for a period during the thirties but was unsuccessful. The probability at the time of writing was that marketing would again be organized by a producers' Board.

Pig production can be quite economically conducted on a small scale and can be efficiently carried on with labour other than that of able-bodied men. It is therefore a suitable business for the small holder, and its importance tends to be greatest on

small farms. This relationship is illustrated by the following figures derived from a survey of the Cotswold area.

Size of Farm	Pigs per 100 Acres
Over 500 acres . . .	15
300 to 500 acres . .	22
100 ,, 300 ,, . .	30
Under 100 acres . .	77

In ordinary times, with feeding stuffs abundantly available, pig-keeping can be carried on largely or entirely on purchased feeding stuffs, so that the scale of the pig enterprise may be largely independent of the size of the farm. Thus expansion of the pig herd is one of the few ways open to the family farmer who has surplus cadital and labour and who is precluded, by the nature of his land, from intensifying his crop production. The chief alternative under such conditions is to expand poultry production. One deterrant to specialization in pigs that has operated in the past has been the risk of epidemic disease, especially swine fever and swine erysipelas. These particular diseases can now, however, be controlled by vaccination. It is true that very small producers suffer from the high cost of feeding stuffs when these are bought at retail by hundredweights. But this disadvantage is not serious if the herd is fifty head or more.

On larger farms there was a marked tendency, in the thirties, to base the size of the pig enterprise on the capacity of one skilled pigman, with or without a lad or other assistant. A suitable size for a one-man unit, for bacon production, with modern labour-saving buildings, is about thirty to thirty-five sows with their produce, *i.e.* 300 to 350 head in all.

Horse-breeding, up till twenty years ago, was a fairly important enterprise on many farms, but the progressive decline in the demand for all classes (except, perhaps, saddle horses and ponies) has resulted in the virtual cessation of commercial breeding. The breeding of hunters and riding ponies is commonly regarded as a hobby.

Poultry form an important department on many types of farm. Fowls are capable of utilizing certain by-products that would otherwise be lost. For example, as gleaners of cereal land after harvest, they are much more efficient than either pigs or sheep,

and they may thus be kept at very little outlay for two or three months of the year. In the utilization of unmarketable grain they are probably quite as efficient as other stock, and on many types of pasture land thay are able to pick up a proportion of food which is not available to other animals.

Highly skilled labour is necessary, but most of the work is of a light nature, so that the industry can provide employment for labour that cannot otherwise be profitably employed. If skilled and interested management can be secured, poultry can be profitably run in small units and the poultry flock is usually an important department on small holdings. On medium and large farms the best course is generally to make the unit large enough to provide full-time employment for one or more special workers. As already noted, poultry and pigs are alternative outlets for capital and labour on farms that would otherwise be below an economic size.

Pedigree Stock-breeding is governed by somewhat the same conditions as those set forth for commercial stock, but two or three other considerations must be borne in mind. A considerably larger amount of capital is needed, partly because the individual animals are more valuable and partly because returns are less certain. Moreover, since pedigree breeding, especially with certain breeds, tends to become a hobby with wealthy people, there is a continual risk of over-production of animals of moderate merit; hence a high degree of skill and expert knowledge are necessary to financial success. On the other hand, the maximum possible returns are far greater than those from ordinary commercial stock, so that there is more scope for skill and enterprise.

THE PRODUCTION OF FOOD FOR STOCK

There remain to be discussed questions regarding the methods to be used in the production of food for stock.

Winter Food.—The following table expresses the average yields [1] of the more important feeding crops in terms of units per acre of dry-matter, starch equivalent, and protein equivalent (see table, p. 876).

As regards the total production of net energy (starch equivalent), it will be noted that cabbage, kale, mangolds, and dried grass

[1] The relative yields of crops vary from one area to another; hence the figures given would not be applicable to particular farms.

head the list. These crops are at the same time probably the most expensive in labour, manure, etc., and therefore they tend to be those grown on the best land and in the vicinity of towns where the animal husbandry is of a very intensive form, *e.g.* milk-selling. At the opposite end of the scale stands meadow hay, the least

	Dry Matter per Acre (Units) *	Starch Equivalent per Acre (Units)	Starch Equivalent in 100 Parts of Dry Matter	Protein Equivalent per Acre (Units)
Turnips (15 tons)	130	75	58	6·0
Swedes (14 tons)	160	98	61	10·0
Mangolds (19 tons)	250	133	53	8·0
Cabbage (18 tons)	200	126	64	16·0
Kale (18 tons)	255	160	63	24·0
Silage—				
Oat, bean, and vetch (8 tons)	240	104	43	13·0
Meadow hay (24 cwt.)	100	37	37	6·0
Clover hay (30 cwt.)	125	48	38	10·0
Dried short grass (45 cwt.)	202	135	66	30·0
Young-grass silage (3 cuts, 8½ tons)	175	110	60	16·0
Oats—				
Grain (18 cwt.)	76	54	70	6·4
Straw (24 ,,)	100	21	21	1·1
Total crop (42 cwt.)	172	75	40	7·5
Barley—				
Grain (20 cwt.)	80	63	83	6·1
Straw (18 ,,)	75	17	22	0·6
Total crop (38 cwt.)	155	80	53	6·7
Beans—				
Grain (16 cwt.)	70	53	76	16·0
Straw (24 ,,)	103	23	22	2·0
Total crop (40 cwt.)	173	76	43	18·0
Potatoes (9 tons)	213	152	78	6·2

* The unit is 1 per cent. of a ton, *i.e.* 22·4 lb.

costly crop to produce, but giving the lowest yield. Hay thus forms the staple winter food wherever extensive methods have to be adopted—on poorer soils and in areas poorly supplied with labour.

The relation of energy value to total dry matter (column 3) has an important bearing on the value of feeding stuffs, varying with the type of animal to be fed and the other feeding stuffs that are to be used in conjunction with the one in question. Roughly

speaking, the starch equivalents of the ordinary types of production rations should bear the following proportions to the dry-matter contents, viz., for pigs, somewhat over 75 per cent.; for sheep, 50 to 55 per cent.; and for growing and fattening cattle, 40 to 50 per cent. Thus, for pigs, grain (especially barley) and potatoes are the only materials that can be largely used in compounding satisfactory rations. Roots and especially fodder-beet can be employed to some extent if they are balanced with more concentrated sources of energy. Hay of ordinary quality is, by itself, insufficiently concentrated to support a high level of production even with cattle and must be supplemented with roots or concentrates or both. Silage, made from the ordinary arable crops cut at the usual stage of maturity, is little better from this point of view. If large quantities of straw are to be utilized for feeding, considerable quantities of roots or grain or both must be used in conjunction; the one exception is the winter maintenance of mature or nearly mature cattle, which can sometimes be done almost entirely on straw. Silage cannot be used as a substitute for roots in such cases because, if sufficient silage is fed for full production, the cattle will consume little or no straw. Under the less intensive systems of farming the object of winter feeding may sometimes be maintenance only and not production. Here the question of the ratio of energy to dry matter is of much less importance, a relatively bulky ration being desirable. Where the protein supply is of importance—*e.g.* notably on dairy farms—the cost of production of this constituent becomes a matter of moment. The cost is usually lowest where leguminous crops are the source, and hence legume hays, silage, and beans have a special value to the dairy farmer. Kale, short-grass silage, and dried short grass are also useful sources of protein. On fattening farms the choice will generally fall to the cheapest source of net energy—often, for example, roots and straw. The foregoing general facts being borne in mind, the choice of feeding crops must depend on a consideration of soil, climatic, and labour conditions.

Mangolds and **Fodder Beets** have a high maximum yield and are thus suited to the better soils: they thrive best where the amount of sunshine is high; they produce relatively heavy yields on deep and rather heavy soils. The labour requirement is high; the growing season is long and the crop is very susceptible to frost damage, so that the seasons of sowing and harvesting are

restricted within rather narrow limits—*i.e.* little latitude is allowed in the seasonal distribution of labour. The last difficulty is, of course, most severely felt in the northern districts, where the season is short. In many districts, too, the crop competes for labour with both the sugar-beet and the potato crops, and both in spring and autumn.

Turnips and **Swedes** are relatively more successful than mangolds on the poorer soils; they require more rain and less sun. As they are specially dependent on fine tilths at seeding, they are unsafe on the heavier soils and in districts liable to summer droughts. The growing season is shorter and the susceptibility to autumn frosts much less, so that they are, relatively, more successful in the north than in the south.

Apart from the question of the direct effect of soil and climatic conditions, there is a connection between the proportion of mangolds to turnips and swedes with that obtaining between cattle and sheep. This is, of course, on account of the fact that turnips and swedes can be folded, and the cost of feeding to sheep thereby reduced. There is a considerable advantage to be gained by growing both crops, firstly because of the better labour distribution that can be obtained by so doing, and secondly, in order to obtain both autumn and spring keep—mangolds being unsuitable for the former purpose but much superior for the latter.

The following table of County Statistics (1939) illustrates some of the foregoing correlations:—

County	Annual Rain-fall (In.)	Mean Daily Sun-shine (July Hours)	Pre-dominant Soil Type	Ratio Cattle to Sheep	Percentage of Feeding Root Area under		Yield Tons per Acre	
					Man-golds	Turnips and Swedes	Man-golds	Turnips and Swedes
Isle of Ely	24	6·7	Fen	2½ : 1	84·0	16·0	26·6	15·1
Essex	23	7·0	Heavy	1 : 1½	66·0	34·0	17·9	9·9
Cheshire	32	6·0	,,	2¼ : 1	34·0	66·0	18·1	15·3
Berkshire	32	6·4	Chalky	1 : 1	38·0	62·0	19·6	11·1
Lancashire	35	6·0	Loam	1 : 1½	31·0	69·0	17·5	15·1
Dorset	38	6·8	Light Chalky	1 : 1¼	21·0	79·0	20·5	11·7
Northumberland	32	5·3	Loam	1 : 6	5·0	95·0	16·1	15·4
Aberdeen	30	5·0	,,	1 : 2¼	0·1	99·9	13·2	13·6

All root crops are, of course, very costly in hand labour, and hence the root area is dependent on the relationship between

wages and live-stock prices. A rise in wages or a fall in cattle and sheep values causes a decline in the cultivation of roots. The large rise in wage rates, without a corresponding rise in live-stock prices, led to a very marked fall in the root acreage between 1900 and 1939. More recently shortage of labour and the rise in wage-rates, coupled with the fact that little progress has been made in mechanization of the crop, have led to a further fall.

Kale and Cabbages, being specially suitable for autumn feeding and having roughly the same soil and climatic requirements as mangolds, are most extensively grown under the same conditions as the latter crop. They are specially valuable where pastures are liable to fail early, *i.e.* in dry districts, and where highly intensive feeding is carried on—*e.g.* on dairy or pedigree stock farms. Kale has the notable advantage over roots that it can commonly be fed *in situ* to cattle as well as to sheep.

Silage from arable crops is of greatest value on the extreme types of soil where either a tilth for roots is difficult to secure or the latter crop is liable to fail through summer drought. It is also worthy of consideration in the wetter and later districts where hay-making and cereal harvesting are frequently expensive and unsatisfactory.

The labour requirement is much less than that of roots but greater than that of hay. The labour is required for sowing at, roughly, the season of cereal seeding, so that the introduction of silage may aggravate a congestion of work at that time. The harvest period in the case of spring-sown crops falls between that of hay and cereal crops, at a time when other work is frequently not pressing; the harvesting of autumn-sown crops may, however, clash with hay-making. Silos are in place on farms where stock is the main department rather than on those where grain-growing is the chief object. They are probably of greatest value on dairy farms.

The capital expenditure for ensilage on a moderate scale, where a tower silo is used, may be reckoned at about £20 per acre of silage grown, resulting in an annual charge of fully £1 per acre to cover interest and depreciation. Where trench, clamp, or stack silos are used and where chaffing equipment can be hired, capital costs are quite small.

Hay.—Apart from silage, hay forms the chief alternative to roots and straw as the basis of winter feeding. Hay is, of course, largely grown in pastoral districts—*i.e.* in regions of heavy soil

and of fairly high rainfall—whereas roots are relatively more important on the lighter soils and the drier climates. Thus in Cheshire there were in 1937 about 15 acres of hay grown to each acre of fodder roots, whereas in Cambridge there were only 3, in Norfolk only 2, and in East Lothian about 1. Where roots are specially reliable and of good feeding quality, *e.g.* in Aberdeen, the area of roots exceeded that of hay.

Hay can, of course, be made from a variety of plants—from annuals such as peas and oats to perennials like lucerne and timothy. Of the plants grown in the more purely arable districts, *i.e.* in leas of short duration, clover predominates in the drier and rye-grass in the moister districts. For long-duration leas, lucerne, either alone or more usually in combination with timothy and meadow fescue, or with cocksfoot, is valuable in areas of light soil and low rainfall. In moister areas, the hay strains of timothy and meadow fescue, in combination with one of the larger types of white clover, probably give the highest yields of nutrients. Such hay leas produce in general much higher yields than the permanent meadows discussed in Chapter I of this section.

The labour required for the hay crop is concentrated in a short period, but is light provided the available labour-saving machinery is used. Where the area is large in proportion to other crops, some casual labour must be obtainable for the haymaking season. Something may be done, especially in the wetter districts, to ease the labour situation by grazing the crops for varying periods in the spring and also by growing a variety of different types. Ryegrass and clover, for instance, are ripe for cutting considerably before timothy or meadow hay. The hay crop is, of course, subject to heavy weather risks, and the average loss of nutritive value, taking one season with another, certainly exceeds 30 per cent. Where the acreage of hay is small in relation to the labour supply there is a strong case for the use of tripods in the curing of at least a part of the crop.

Grass Drying.—Artificial drying is by much the most efficient method of conservation in the sense that loss of nutrients is reduced to an almost negligible proportion. The figure is commonly of the order of 2 or 3 per cent., which compares with average figures of about 25 per cent. for silage and perhaps 40 per cent. for hay. But the high cost of artificial drying can be borne only if the product is of first-class quality. Even in this case the economics of the process depend upon the market prices

of high-protein and medium-protein concentrates. There is a limited demand for high-quality dried grass as a source of carotene in animal rations.

Grass Silage.—The ensilage of short young grass, though the process involves a loss at best of about 20 per cent. of the nutritive value of the herbage, gives essentially the same kind of product as artificial drying—*i.e.* a concentrated and protein-rich food with a high vitamin A potency. The capital cost of equipment is, of course, very small compared with that of a grass-drying plant. The partial substitution of ensilage for hay-making reduces the labour peak in the hay-making season on grass farms.

Oats.—Cereals must almost necessarily occupy a fairly large place in any system of arable farming because of their low cost of production when grown in conjunction with other crops. Moreover, a certain proportion of concentrates must be employed in compounding most types of rations, and the cereal grains form, broadly speaking, a good and cheap source of energy in concentrated form. Ordinarily, the practical question for the arable farmer is not whether cereals shall be produced but whether the grain grown shall be consumed on the farm or sold and replaced by purchased concentrates. The answer to this depends on the relative market values of home-grown grain and market concentrates and on the transport costs involved in making the exchange. Hence in the later and wetter districts where the crop is of relatively low market value, and again where markets are not easily accessible, it will often be profitable to use the home-produced grain for feeding. Oats form by much the most important cereal for stock-feeding purposes. For horses, cattle, and sheep, the grain forms a healthy, palatable and, broadly speaking, a well-balanced food, but for pigs the fibre-content is somewhat high. The straw yield is relatively large and its feeding quality, particularly when the crop is grown in the cooler and moister districts, is high.

Barley grain has a higher energy value than oats; it is less suitable for horses but more valuable for pigs. The straw is less in yield, and perhaps on the average of lower feeding value, though in the drier and sunnier districts, where oats do not flourish, the latter statement does not hold good. Broadly speaking, barley is grown as a substitute for oats on the thinner and drier soils and in the drier districts, and again in regions very far north where the growing season is very short. Where the end in

view is stock food, the varieties that are cultivated in both cases are frequently different from those that are preferred where marketable grain is the object. In oats, particular attention is paid, in feeding varieties, to the yield and quality of straw, and in barley a high nitrogen-content should be aimed at as opposed to the low nitrogen-content desired for malting. Six-rowed winter and four-rowed early maturing spring varieties are commonly cultivated only for feeding.

Wheat is regularly used as a feeding stuff for poultry, but for other classes of stock it has no special merits, and has been used only in times when it was procurable at a low price in relation to maize, oats, and other feeding grain. In times when the grain is very cheap it may constitute 50 per cent. of pig feeds and perhaps 25 per cent. of the concentrate mixtures for sheep and cattle. The straw is of very low energy value. Rye is still less desirable from both points of view.

Beans, as appears from the table on page 876, are specially valuable on account of their high production of protein. They are therefore rather largely grown on dairy farms wherever the soil is adapted to their needs. In the period of 1930-39, imported high-protein cakes, such as earth-nut, soya-bean, and cotton, were available at prices so low as to make bean-growing unprofitable. The cultivation of the crop revived during the war, but has declined again as increased quantities of imported high-protein feeding stuffs have become available.

Total requirements in the matter of winter foods depend, of course, on the length of the winter season. They are, for example, relatively high in the north-east and low in the south-west of Britain.

Summer Food.—It has been already mentioned that, on the whole, cattle and sheep can be maintained in summer more cheaply on pasture than on arable crops, whereas in winter arable-land products often form the more economical source of food. Hence there is a considerable migration of stock from pastoral to arable districts in autumn and back again in spring. Even in mainly arable districts, where it is necessary to maintain stock (such, for instance, as dairy cows or breeding flocks of sheep) during summer, it will generally be found that for part of the growing season pasture will form the cheapest food. The system of pasture management that is calculated to give the best returns depends on conditions. The poorest and highest mountain pastures will not give an

adequate return either for fencing or manuring—or, indeed, for anything but the least costly improvements. Grass that is worth a few shillings per acre is generally most economically managed in large enclosures, and will rarely pay for any manures other than the cheaper forms of phosphate, *i.e.* mineral phosphate or slag. Fattening pastures are always intensively managed from the labour point of view, but there is often little scope for improvement by manuring. The intensive system, involving strip grazing and frequent nitrogenous manuring, offers the best prospects of success on grassland of moderate fertility, particularly where, owing to its economic situation, it commands a relatively high rent. It is more successful in districts of high than of low rainfall and is more easily applicable to milking cattle than to other classes of live stock.

Arable forage crops grown for soiling or for folding may be used in greater or lesser measure as a substitute for pasture.

Generally speaking, cultivated forage crops are somewhat more productive than pasture, but the cost of production per acre is higher. Hence the cultivation of the former will tend to be carried on where the natural and economic conditions favour intensive methods, *i.e.* near markets and on the better sorts of land. Generally, it is only under such conditions that pasture forms no part of the summer food. Apart from this a regular supply of food can be assured only on the lighter classes of soil and in districts of fairly high and evenly distributed rainfall, because elsewhere it is impossible to accomplish the necessary cultivations at the right seasons or to rely on the regular germination of the seeds sown. The cultivation of perennial forage crops, such as lucerne, which are much less dependent on regular rainfall than annual forage crops, is of material assistance in a summer soiling or folding system. A silo, in which surplus produce may be stored against seasons of scarcity, is also of great advantage. A short growing season is a further obstacle to the cultivation of summer forage crops, because under such circumstances full production can be assured only by sowing all crops in spring and harvesting in autumn. Forage crops for summer feeding are therefore much more widely cultivated in the south than in the north.

As supplements to pastures, particularly during the spring and autumn seasons, arable forage crops are of much greater importance. In the milder districts the growing of autumn-sown

catch-crops, such as rye, crimson clover, winter vetches, etc., makes possible the feeding of full production rations during the transition period from winter feeding to pasture. Again, especially in dry districts where pastures fail early in autumn, spring-sown forage crops—such as rape, kale, spring vetches, early cabbage, maize, etc.—enable full production to be maintained until regular winter crops are available. This is, of course, possible on almost any type of arable soil, as witness the cultivation of many of the crops named on the heavy soils of Essex. Kale has the notable advantage that it lends itself to strip-grazing with cattle and that, being relatively frost hardy, it can be relied upon for a greater or smaller proportion of the winter period—up till Christmas in many areas and considerably longer in the milder areas.

CHAPTER III

SYSTEMS OF FARMING

I.—THE CO-ORDINATION OF ENTERPRISES

SUPPOSING that one has formed an opinion regarding the commodities that might be economically produced under a given set of conditions, one's next problem is that of fitting together the separate enterprises into a general scheme that can be economically run as a whole. It is necessary to state some of the guiding principles that have to be kept in mind when this is being done.

Seasonal Distribution of Labour

Wages, on most farms, constitute the largest single item of expenditure, and it is convenient to take the labour organization as the starting-point in constructing the farming system. The essential ends to secure are that there shall be productive work for all the labour that is employed at any particular season, and that sufficient workers shall be available to perform in due season all the work that falls to be done.

Under a majority of circumstances the cost of labour in relation to its quality is lowest when constant employment is given. Exceptions are to be found where other industries—such, for example, as forestry or fisheries—offer seasonal employment; under such circumstances it may happen that labour can be obtained at a cheaper daily rate if the worker is offered a seasonal rather than a yearly contract. But in general, casual labour is relatively expensive, and in many cases skilled casual labour is virtually unobtainable at those seasons when it would be required. The working of overtime in busy seasons is, of course, another alternative, but overtime scales of pay are naturally higher than ordinary rates, and the working of much overtime inevitably leads to some loss of efficiency. Hence the seasonal distribution of farm work must always receive careful consideration, and seasonal demands must be levelled up to such

an extent as to make the labour as productive as possible in relation to its cost.

The same considerations apply to horse labour, but this on most farms has become a relatively minor item in total costs. The cost of running a tractor, per working hour, will of course vary immensely with the number of hours worked, but the cost of maintaining an idle tractor is small.

The operations of the farm, regarded from this point of view of the seasonal distribution of work, may be roughly grouped in four categories, viz.:—

1. Such as have to be performed regularly, as a matter of daily routine—*e.g.* milking and the feeding and tending of live stock.

2. Such as can be efficiently or successfully performed only within narrow limits of time, and may be, in addition, dependent on weather conditions—*e.g.* hay-making, cereal harvest, mangold and potato raising, seeding of spring crops, singling of roots, etc.

3. Such as fall to be carried out at certain approximate periods of the year, but are not strictly limited as to time and weather—*e.g.* winter ploughing, storing of swedes, carting of farmyard manure.

4. Such as can be equally well performed at any season or in any weather—*e.g.* road mending, building repairs, and the overhaul of implements, machinery, and other equipment.

Operations in the first category present little difficulty except the unavoidable one that they have to be performed seven days a week; the last group usually presents no difficulty at all. It is the other categories, and particularly the second, that must receive careful attention when the general system is being worked out. Broadly speaking, a large proportion of any one crop leads to difficulty in organization because there is usually an optimum time for each operation—seeding, harvesting, etc.—and hence too large an area will involve either the employment of casual labour at generally high rates or the spreading out of the necessary work beyond the desirable time limits. As an example of the working out of the seasonal distribution of labour we may take an east coast arable farm, growing a fair variety of crops, and farmed, say, on the East Lothian six-course rotation of (1) spring oats, (2) maincrop potatoes, (3) winter wheat, (4) turnips, swedes, and sugar-beet, (5) barley, and (6) one year ley for hay and silage.

The following might be approximately the normal dates of the more critical operations:—

Oat sowing	7th to 21st March.
Barley sowing	1st March to 15th April.
Potato planting	1st April to 1st May.
Root sowing	20th April to 20th May.
,, thinning	1st to 25th June.
Ensilage	7th to 20th June.
Hay-making	25th June to 10th July.
Summer cultivation of potatoes and roots	Till 20th July.
Wheat, barley, and oat harvest . .	10th August to 25th September.
Potato lifting	1st to 20th October.
Wheat sowing	25th October to 30th November.

While the labour distribution obtained on this system is, on the whole, very satisfactory, the following disadvantages and difficulties fall to be noted:—

1. There is a large preponderance of spring-sown crops, with the result that there is frequently great pressure of work in April. Late sowing of barley is a common consequence, particularly where roots are fed off late. Casual labour must generally be obtained for potato planting, but this need not be skilled.

2. Root thinning will often clash with ensilage and, if germination is delayed, with hay-making. Further, successive sowings of roots may "come to the hoe" simultaneously, and casual labour may be required to ensure timely singling.

3. There is liable to be a gap between the completion of summer cultivations and of hay harvest on the one hand and the commencement of cereal harvest on the other; all the cereal crops tend to ripen together, making the harvest a time of great pressure. The introduction of a proportion of early potatoes or of spring-sown silage crops would bring useful work into the slack period mentioned, without, however, easing the problem of the cereal harvest. But harvest pressure can be relieved if part of the area is harvested by combine. The substitution of winter for spring oats serves both ends, but apart from the fact that winter oats are not entirely reliable in the northern areas, the preparation of the land for this crop involves the loss of the hay aftermath.

4. The late ripening of the potato crop, taken in conjunction with the possibility of severe early frost, makes the potato harvest an exceedingly pressing business, and there is frequently great

competition for the available pickers. By following the potato crop with wheat, the seeding of the latter crop is liable to be unduly delayed. Occasionally no opportunity of sowing wheat occurs, and there is a certain derangement of the system through the substitution of a spring cereal.

Difficulties such as those in the foregoing example are found in most systems. Not only is it impossible to plan a perfect distribution of labour that would adapt itself to all probable seasonal variations in weather conditions but the question is only one of many that have to be considered, and imperfections in one direction must be accepted if there are compensating advantages in some other.

Fig. 42 illustrates an actual case of seasonal distribution of man labour on a mixed farm in the Midlands about the period 1925. The total area was 540 acres, of which, in the year in question, 290 acres were under arable crops and 250 under permanent grass. On the acreages of the several crops grown and the numbers of stock kept, the labour requirement at the period might have been estimated at just over 5000 man-days—equivalent to the full time of 17 men. The staff regularly employed was 16 men and 2 boys.

The chart shows that the labour distribution was fairly even, the extra time devoted to the live stock in winter being roughly balanced by the greater requirements of the arable in summer. Miscellaneous labour was fairly uniform throughout, showing that there was no period when it was found necessary to resort largely to "fill-time" jobs. A large number of casual hands had to be employed for a short time in lifting potatoes, but such employment is generally unavoidable. There were peaks, too, at the time of potato-planting (April to May), and again in July when root-thinning clashed with hay-making. Broadly speaking, however, the organization was successful from one point of view—that is to say, productive work was available for the whole staff at all seasons of the year.

Judged by the other test—the timely performance of important work—the organization is seen to have been faulty. Potato-planting was not finished until mid-May; in May and June a great deal of time had to be devoted to the weeding of corn crops. Such work has, of course, been eliminated by the introduction of chemical weed-killers. Hay-making had hardly begun in June and continued until August (overlapping, in fact, with the corn

harvest), with the implication that much of the hay must have been far past the optimum time for cutting. Summer tillage of roots continued till the end of August, long after harvest was in full swing, and the harvest itself was not completed at the end of September. Moreover, the number of working hours recorded was consistently higher than normal. It is clear that there was

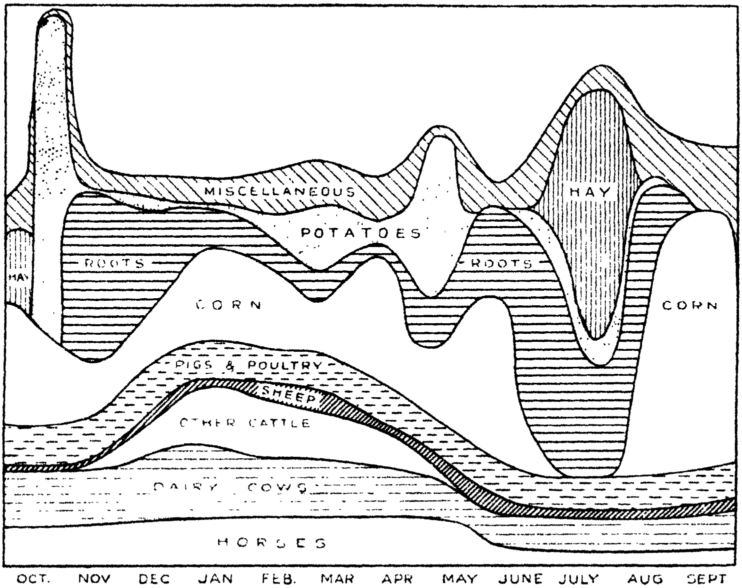

FIG. 42.

always more to do than could be comfortably managed, and that overtime must have been the rule rather than the exception. Either, then, the regular staff was inadequate, or else its organization was inefficient. In cases such as this, where work is chronically "behind the calendar," it sometimes suffices to get some tillage done by a contractor, enabling the regular staff to overtake arrears; apart from the obvious and immediate advantage of such a step the psychological effect on the farm staff is often very beneficial; workers inevitably lose heart when the work of the farm is badly behindhand.

Labour distribution is affected not only by the proportions of the various crops grown but also by the order of their succession in the rotation. Obviously one must aim at allowing sufficient time for the necessary cultivations between the harvesting of one

crop and the sowing of the next, with a certain margin against the possibility of unfavourable weather. For example, where roots are left on the land for winter folding, the choice of a crop to succeed them is limited to such as may be sown fairly late in spring; or again, if aftermaths are wanted for autumn grazing, they cannot, in many districts, be followed by winter wheat.

Weed Control

A second requirement that any permanent scheme of farming must fulfil is that it should provide means for the control of weeds. A clean farm is one of the chief marks of an efficient farmer, but this end, like others, must be attained with due regard to economy. There are five chief methods of control.

1. *The Use of Smother Crops.*—Here the object is to suppress the weeds through the agency of the competition of the crop. Kale, silage crops and late potatoes are perhaps the most useful from this point of view because, with such, a dense, luxuriant vegetative growth is desirable in itself. On the other hand, barley, for example, does not lend itself to such use, because great vegetative luxuriance is incompatible with high quality of the produce. The smothering effect of cereals depends mainly on the length of straw, which is related to the density of the shade cast. Short straw may be desirable from other points of view, but a compromise may be sought in the case of foul land. Obviously, the greatest degree of reliance can be placed on this method where the land is fertile, where the moisture supply is fairly abundant, and where, owing to favourable economic conditions, a somewhat intensive system is justified. On poor, dry soils the method has a very limited application.

2. *The Alternation of Arable Crops with Grass, and, in certain cases, of Hay with Pasture.*—The particular weed species that flourish in the one type of environment generally die out more or less rapidly in others. Thus charlock and runch multiply in spring corn, while slender foxtail, wild onion, and corn buttercup increase in winter corn; yellow rattle and soft brome are weeds of meadows; and ragwort and creeping buttercup of pastures. Alternate husbandry is generally to be regarded only as an aid in weed control, other and more active measures being usually necessary in addition. A ley-and-corn rotation, without row crops, is practicable in some areas. Ordinarily two or three corn crops are followed by three or more years under grass, the

ley being used for hay (timothy, timothy-fescue mixture) or for grazing, or both. In many areas it is desirable to break up the ley at midsummer, so that the land may be bastard-fallowed in preparation for the first corn crop. With full mechanization, the system is highly economical of labour.

3. *The Inclusion of Row Crops in the Rotation.*—This has long been regarded as the chief method on all the lighter and medium soils in this country—on all soils, that is to say, where potatoes, roots, kale, etc., form reasonably reliable crops. Any crop may, of course, receive a certain amount of intercultivation, but it is only where the individual plants are fairly large, permitting the use of horse implements, or of tractors with row-crop equipment, between them in their early stages, that such intercultivation can be carried out at a moderate cost. At the best, the amount of hand labour required is heavy, and it is only where intensive systems are justified that frequent row crops can be profitable. Generally, a proportion of one cleaning crop to two cereal crops provides ample opportunities for weed suppression; and a less proportion than this will usually make for difficulty unless use be made of some of the other methods of weed suppression—such as stubble-cleaning or chemical weed-killing. Much, however, depends on the type of soil, well-drained and fertile clays being notably less liable to weed infestation than sandy or chalky soils.

Row crops, of course, will fail to prove effective if the young plants fail to compete with the early growth of weeds. Sugar-beet, and particularly carrots, are easily smothered by weed competition.

4. *Cultivation in the Absence of a Crop.*—Such cultivation may be carried out in the same season that an ordinary crop is grown (spring or autumn cleaning); it may extend over a part of the ordinary growing season, the remainder being occupied by a quick-maturing crop such as a single cut of hay or a green forage crop (bastard fallowing); or finally, it may extend over a full season (bare fallowing). The first of these methods is obviously limited in its application by climatic conditions. In the colder and wetter districts the ordinary cereal crops must be sown as soon as the ground becomes workable in spring, and are harvested so late that little or no autumn cultivation is possible; whereas in the south, where harvest is early, a great deal of cleaning may often be accomplished in autumn.

Bastard fallowing involves the sacrifice of part of the summer season. Hence, in districts where the amount of summer heat and sunshine constitutes a limiting factor in production, it becomes a costly operation. There are other districts, however, of low rainfall and of long and hot summers, where the limiting factor, so far as climate is concerned, is not heat but moisture. In such cases the soil may be able to store up most of the rain that falls during the period of the fallow, and the partial sacrifice of one crop may be justified by the increase obtained in that which follows. Hence it is that in the south-eastern counties the bastard fallow is often an economical method of weed control. Another form of partial fallow, widely used in the chalk and limestone areas, is, in effect, a spring fallow followed by rape—or, more commonly, a crop of kale or turnips—sown in June or July.

Bare fallows, too, may be introduced for other purposes than that of weed control. In dry-farming systems they are employed with the object of storing up a season's rainfall, on the principle of using two years' rain for one year's crop. Again, at the polar limits of arable cropping they become necessary because there is not time, within the limits of a single season, to prepare the land and also to grow a crop. Under our conditions bare fallows are useful in that they expose the soil to weathering agents and lead to improved tilth, but their chief object is that of cleaning the land. On all soils except heavy clays, the bare fallow is regarded as a last resort in the struggle against weeds, to be used only where other methods cannot be employed—that is to say, where neither roots nor potatoes can be planted with much chance of success. Ill-drained clays require the most frequent fallows both because they quickly become foul and because opportunities for spring and autumn cultivations are very limited. The acreage of bare fallow fluctuates widely from year to year, rising in seasons when the spring is unfavourable for tillage. The fallow acreage in England and Wales was as high as 535,000 in 1937 but is now ordinarily about 200,000.

5. *The Use of Herbicides*, which has increased rapidly with the growing range of materials, has greatly widened the farmers' choice of cropping systems—enabling weed control to be achieved with much less resort to fallows and row crops. At the time of writing, however, certain weed species—*e.g.* wild oat, couch, and other stoloniferous grasses and bracken—could not be controlled by any practicable chemical treatment.

The Maintenance of Soil Fertility

Humus.—The importance of maintaining an adequate organic-matter content in arable soils is well recognized. Under certain special sets of circumstances—for example, on black fen soils, or where plentiful supplies of organic manures such as sea-weed or city refuse are available at low cost—the farmer may be free to grow such crops and to dispose of them in such ways as will bring the greatest immediate returns. But under many circumstances he must arrange that a greater or less proportion of the organic-matter of his crops is returned to the soil as manure. The precise proportion that should be maintained between sales and home consumption, in order to secure, in the long run, the maximum net return, is very hard to determine. It depends, for one thing, on the physical characteristics of the soil. On deep, well-watered, alluvial lands like the Scottish carses or the Lincolnshire silts, considerable amounts of hay and straw, as well as grain, etc., may be sold off year by year with very little harm. On the other hand, thin light soils on chalk, and those of sandy or gravelly nature, as well as the stickier clays when occurring in dry districts, fall off in cropping power if a large proportion of the organic matter that they produce be not returned to the land. It depends, too, on the staple crops of the farm. Wheat, owing to its deep-rooted habit and to its relative indifference to tilth, is much less dependent on the humus-content of the soil than, say, oats, with their high moisture requirement and shallower root system.

The necessary supply of humus may be provided (1) by green manuring, (2) by the folding of animals on annual forage crops, (3) by laying the land away to temporary pasture, or (4) by the application of farmyard manure or compost. In most actual cases two or more of these methods are used in conjunction. Under green manuring we may include the ploughing in of crop residues such as sugar-beet tops and the leaves of other root crops, which is a widespread practice, and also the ploughing in of clover or seeds aftermath, which is done to some extent on farms that carry little live stock in summer. The crops specially grown for green manuring are normally catch-crops, because the sacrifice of a full season's crop for this purpose can rarely be justified. Hence the conditions under which green manuring becomes a part of the system are those under which catch-crops are likely

to succeed, viz. light soil, fairly abundant rainfall, and mild winter climate. Even where catch-crops succeed it will ordinarily be desirable to feed them off rather than to plough them in directly. The yield of catch-crops is, however, uncertain, and their utilization for feeding may involve large market transactions in live stock, in which case transport charges and sales commissions may be likely to amount to more than the crop is worth. The type of plant used for green manuring requires some consideration. Very highly nitrogenous material, such as immature clover or vetch, decomposes with such extreme rapidity that the nitrogen may be lost, as nitrate, before the following crop is able to make use of it; moreover, under the highly aerobic conditions prevailing in light soils the bulk of the organic matter is quickly dissipated. Thus it would seem that where a cereal is under-sown with the idea of producing a sward to plough in, a mixture of Italian ryegrass with clover or trefoil may be preferable to a legume alone. The carbon-nitrogen ratio of the material to be ploughed in may be still further widened by leaving a long stubble when the cereal is harvested. In special cases the use of a full-season crop for green manure may be profitable. Many horticultural crops are much more exacting in the matter of tilth and soil moisture conditions than the general run of farm crops. With the diminishing supplies of stable manure, etc., increasing use is being made of composts and green manures, the most widely used species for the latter purpose being Italian ryegrass sown at a high seed-rate.

The grazing of temporary leys and the folding of summer forage crops are to be regarded as alternative methods of serving the same ends—the provision of summer food for stock and the direct return to the soil of a large proportion of the organic matter produced. The cultivation of annual forage crops for summer folding involves more or less continuous cropping, and the main conditions which render this possible are a free-working and well-drained soil and a moderately high and evenly distributed rainfall. Under such conditions arable forage crops are more productive than grass, though the labour charges are necessarily much higher and the cost of seed is greater. On heavier soils, as well as where the growing season is shorter and the rainfall less evenly distributed, the grazed ley is usually preferable. Arable folding has declined greatly in recent years with the rising cost of labour in relation to the value of farm produce.

The folding of summer and winter forage crops and the grazing of leys tend to predominate in the less intensive arable systems and where live stock occupies a position of primary importance in the farming scheme. These methods permit of the maintenance of fertility at a cost sufficiently small to be in keeping with the rather low gross income obtained from the land. On the most valuable arable soils such methods interfere with the primary object in view, which is the production of marketable plant products. In such cases the live stock must be maintained chiefly on the by-products of the system, and house-feeding of stock, with the production of farmyard manure, becomes the chief means of keeping up the humus-content. The handling and transport of large quantities of feeding crops and dung is a costly business, and can pay only when the gross income is kept at a high level.

Phosphates.—The problem of maintaining the chemical fertility of the soil is more or less bound up with that of the upkeep of the humus-content, because all organic manures contain quantities of phosphates, potash, and nitrogen. As regards phosphatic fertilizers, it is easy to lay down a general policy. Practically all systems of farming involve the removal of phosphates from the land, and it is the exception to find a soil that can be farmed successfully over a period of years without recourse to phosphatic manures. These are relatively cheap, and they do no harm when applied in quantities somewhat larger than are necessary. Large single applications may be undesirable because, especially in acid soils, the phosphate forms highly insoluble compounds with iron and aluminium; but in general, phosphates should never be allowed to become the factor limiting production but should be applied almost up to the limit of their capacity to produce yield increments. Harm has been shown to have resulted from excessive use of phosphates on intensively cropped market gardens, and particularly in greenhouses.

It is difficult to lay down any general guidance about the quantities required to maintain full productivity, since soils vary in their capacity to fix phosphoric acid in unavailable forms. Occasional determinations of "available" phosphate are a valuable guide to the level of application required, though even with such information it is well to carry out occasional field trials to discover the response actually obtained. On most British soils a substantial saving can be obtained by the use of combine drills and other equipment for placement of fertilizers.

Potash.—With potash the position is somewhat more complicated. Where only live stock and their products are sold off the farm, the drain of potash is negligible; even when grain is sold as well, the loss is comparatively small; but when potatoes, roots, and hay are sold in addition, the loss becomes considerable. A good crop of potatoes, for example, removes as much potash as is contained in 2 cwt. per acre of the sulphate. Different soils, too, show very different potash requirements, heavy soils generally making little or no response to applications, while sandy and peaty soils, chalk lands, and gravels often show very marked responses. Again, it is possible to economize in the use of potash manures by care in the conservation of dung and urine and by growing especially deep-rooted species that reach down to subsoil reserves. For practical purposes potash may be considered as not liable to be washed out of the soil, but on some soils there is a material loss by fixation. In such cases, again, an economy can be achieved by placement. In general, the principle to be followed is the same as in the case of phosphates. It is generally most profitable to meet the demands of the plant in full, and it is safer to err in the direction of excess rather than in that of deficiency.

Nitrogen.—The economic aspects of nitrogen usage are somewhat complex because supplies of soil nitrogen are obtainable from three separate sources, *viz.*: (1) the leguminous plant, (2) the residues of purchased feeding stuffs, and (3) nitrogen fertilizers.

The introduction of clover, as a regular rotation crop, was the first step, in point of time, towards the provision of adequate supplies of soil nitrogen. Later came imports of guano and natural nitrate, together with some quantity of by-product ammonia from gas works, etc. At about the same period (mid-nineteenth century) came greatly increased imports of oil-seeds, particularly linseed, which were fed to live stock not only with the object of obtaining well-balanced rations but with a view to the production of nitrogen-rich manure. Up till the twenties of last century supplies of imported high-protein feeding stuffs continued to be large and prices continued low, while nitrogen fertilizers were relatively scarce and costly. Hence British farmers continued to rely, in the main, on legumes and cake-fed dung. Since that time there has been a rapid expansion in the output of synthetic ammonia and nitrate, at low cost, while

imports of protein feeding stuffs have fallen and prices have risen. The consequence has been a large increase in the use of nitrogen fertilizers.

Farm practice has, however, changed too slowly, and the average rate of usage in Britain was still, at the time of writing, substantially below that which would have yielded the maximum profit. Moreover, modern crop varieties, particularly of cereals, are capable of responding to, and of repaying with profit, higher applications of nitrogen than the sorts which were formerly available; and there has been a time-lag in adjusting the level of nitrogen usage to the changed character of crop plants.

With regard to the nitrogen residues of feeding stuffs, there are, of course, numbers of farms—heavily stocked dairy holdings and those with large pig units—where purchased feeding stuffs are bought in large amounts. But with modern standards of dairy hygiene, conservation of the cow manure is commonly very poor. Purchased feeding stuffs can indeed constitute a source of fertilizer nitrogen, but it is no longer economic (as it once was) to feed protein in excess of the animals' needs in order to produce nitrogen-rich manure.

Turning to the place of legumes, it is important that pulse crops—peas and beans—are relatively very inefficient in nitrogen fixation. Moreover, their residues (roots and root nodules) are quickly nitrified between harvest and the onset of winter, and the nitrate is largely lost in the winter drainage. It is only the herbage legumes—clover, lucerne, sainfoin, etc.—that add substantially to the stock of soil nitrogen, and their efficiency is increased when they are grown in association with grasses. A well-balanced clover-grass sward has been known to raise the stock of soil nitrogen by an amount equivalent to that contained in a dressing of 10 to 12 cwt. of ammonium sulphate per acre. Thus with the introduction of truly perennial types of herbage legumes (especially white clover) it became possible, under a six-course rotation including a three-year ley, to maintain quite a high level of production with little resort to nitrogen fertilizers. Indeed, under this system to-day the use of "artificial" nitrogen is resorted to only for limited purposes, *e.g.* to ensure the establishment of the ley, to produce "early bite" on a proportion of the leys and for such "gross feeding" crops as kale and mangolds.

Two systems of farming, however, rely mainly on fertilizers. Under intensive arable cropping, with little live stock, nitrogen fertilizers may be profitably applied, in considerable amounts, to all crops except beans and peas; optimum (most profitable) dressings are ordinarily between 2 and 4 cwt. per acre. The other case is that of intensive grassland farming (see pp. 473 to 477). A system based on carefully selected plant material, utilized by strip-grazing with grass drying or ensilage, can give profitable returns, in the form of milk, for successive applications of nitrogen fertilizer in amounts totalling 5 to 8 cwt. per acre per year.

Lime.—The maintenance of soil fertility also involves the control of soil acidity, which is generally best accomplished by means of fairly frequent and moderately small dressings of lime. Heavy dressings at longer intervals involve the sinking of additional capital and increased wastage from the soil, without any compensating advantage. Considerable economies in lime may be effected by the continuous use of "lime-saving" or lime-containing fertilizers, *e.g.* nitrochalk in preference to ammonium salts, and basic slag or mineral phosphates in preference to superphosphates.

In certain high-rainfall areas, where leaching is increased by the sulphuric acid content of the rain (as happens in smoke-polluted areas), the rate of loss of lime from near-neutral soil (pH 6·5) is so high that the cost of maintaining the lime status at this level may be prohibitive. This is particularly likely where other factors, such as climate, set a somewhat low limit to the productivity of the land. In such cases the only economically possible course may be to restrict cultivation to those species, such as oats, potatoes, and grasses, that show a high degree of tolerance to sour conditions, and to abandon the attempt to cultivate barley, sugar-beet, red clover, etc.

Plant and Animal Hygiene

The control of diseases and pests, both of crops and of live stock, is one of the constant concerns of the farmer and must receive due consideration in relation to the general farming scheme. When the natural mixed herbage of the ground is replaced, say, by a crop of swedes, or when the natural animal population is replaced by a flock of sheep, the farmer is disturbing

the balance of nature and is giving to the enemies of these particular species an opportunity, such as they never enjoy under natural conditions, to increase and multiply. Sometimes the consequences are not serious; thus healthy crops of mangolds or barley can, with reasonable care, be produced for several years in succession on the same land; and pastures may be stocked entirely, season after season, with fattening cattle, without any particular ill consequences to the animals.

Even when pests are potentially very harmful it may be cheapest and best to deal with them directly. Thus no farmer would think of modifying his general system of farming because of bunt attacking his wheat or scab his sheep; in both cases there is a cheap and satisfactory method of control. In other cases direct measures are only partially successful. For example, liming is useful against finger-and-toe in *Brassicas*, but it may be necessary, in order to keep the disease completely suppressed, to grow susceptible crops only at long intervals. Similarly, husk in young cattle may be treated directly with some measure of success, but it is better, where possible, to avoid infection by arranging to have aftermaths or catch-crops for autumn grazing. If these cannot be economically produced it may be best to house the animals and give up grazing altogether. Lastly, there are cases where no direct method of control can be economically applied, and where attack can be escaped only by introducing more or less fundamental changes in the farming scheme. Thus, if land becomes infested with potato eelworm, there is at present no satisfactory method of control except the adoption of a rotation in which there is a minimum interval of four or five years between successive potato crops. In other areas the farmer may be obliged to reduce his corn acreage because of a "build-up" of cereal root eelworm, or increasing incidence of such diseases as "eye-spot" and "take-all"; and in still others he may have to restrict the size of his flock or adopt a system of alternate husbandry because his land becomes "sheep sick." In general there is least trouble with crop pests where a long rotation is adopted, and least with animal pests where a mixed stock is kept, where the animals can be given rather frequent changes of pasture, and where the pasture includes a high proportion of ley.

II.—EXAMPLES OF BRITISH FARMING SYSTEMS

The following descriptive accounts, with relative financial data, are given as illustrations of the general principles of farm organisation. The prices, wage rates, etc., are those of 1955.

I.—North Wales—Mountain Sheep Farm

Natural Conditions and Land Use

The typical Welsh mountain farm comprises, firstly, a small area of arable land round the homestead, which is commonly on the lowest part of the farm and at no very great altitude; secondly, a larger block of enclosed land (known as the *ffridd*) stretching up to perhaps the 1000-ft. contour and sometimes including a proportion of improved or improvable land; and thirdly, a still larger area (or, alternatively, common grazing rights for a prescribed number of sheep) on the highest land.

Rainfall varies greatly according to elevation and aspect and may reach 70 in., and even 100 in. on the western aspects of the higher slopes. Winter in the valleys is relatively mild, but on the high ground snow may lie for long periods.

The soils on the steeper slopes are thin, stony, and heavily leached, and here the herbage, despite the high rainfall, is liable to suffer from drought. The herbage consists mainly of *Nardus* (wire grass) and Sheep's Fescue. On gentle slopes lying below steeper ones the soil is well supplied with seepage water, and here the dominant species is commonly *Molinia*; where drainage is impeded there are accumulations of peat, with typical mountain-bog flora. The deeper and more fertile land, up to elevations of some 1200 ft., is very liable to invasion by bracken. In the absence of steep slopes, rock outcrops and boulders, such land may be ploughed, limed and fertilized and, after one or two pioneer crops of rape, etc., be reseeded with good grasses. The typical soil of the valley bottoms is a silty loam.

Economic Situation

The area is thinly populated and, apart from stone or slate quarrying in certain localities, stock breeding is the only important industry. Main highways are few and minor roads are generally poor. Many farms are without piped water supplies or electric power. Most are small, some too small to provide full-time employment for the farm family. The following description applies to one of the larger.

Allocation of Land and Stocking

The total extent of the holding is about 1300 acres. The enclosed arable, round the homestead, is 40 acres and is divided into small fields. It is farmed on a long-ley rotation, with some 10 acres annually under oats,

rape, etc. The leys are grazed in early spring by the weaker ewes, and the later growth is mown for hay or silage. The flock may have to be gathered to the enclosed land during periods of snowstorm and be fed on hay. The rape is ordinarily used for fattening the most forward of the wether lambs.

The ffridd extends to some 240 acres and is in a ring fence. At the time of writing, 10 acres had recently been enclosed and reseeded (as part of a scheme under the Hill Farming Act), and a further area was due to be similarly improved.

The open mountain is legally common grazing, but in the present case, as in many others, the flock of each owner is trained to keep to its allotted area.

The whole flock is run on the open mountain from early June until weaning time in late August. At mating time, again throughout the lambing period, and also at times when snow threatens, the ewe flock is confined to the ffridd. Otherwise, during winter, the sheep have the run of both this and the open mountain. Some hay is usually mown on the better patches of the ffridd. The ewe lambs that have been retained for flock replacement are sent to lowland pastures for wintering, leaving in November and returning in April. The rams are kept in the enclosed fields from September until mating time in November.

Apart from the flock of Welsh Mountain Sheep the only live stock is a herd of twenty Welsh Black cows, mated to a Hereford bull, some twenty or thirty poultry, and a "house" cow.

Rental

Rental values are governed not by acreage but by such factors as the stock-carrying capacity of the farm, the average death-rate among the ewes, the normal lambing percentage, the risk of major losses (mainly by snowstorm), and the average size and quality of the lambs. Figures vary from 2s. or 3s. per ewe on the poorest grazing to 6s. or 7s. on the best—leaving out of account those farms which are capable of wintering their ewe lambs or of fattening a substantial proportion of the wether lambs. The cost of low-ground wintering for the normal quota of ewe lambs frequently exceeds the rent of the farm. Middle-grade farms, such as the present example, are stocked at a rate of one ewe to every 2 or 3 acres of total area.

Labour

Five or six hundred ewes provide full employment for a shepherd who, however, requires a whole-time assistant during lambing and occasional help at other times. In the present example the farm staff consists of the farmer himself and two paid workers.

Tenant's Capital

The following estimate of the investment (at 30th September) is based on the assumption that the wether lambs and surplus ewe lambs have been sold, while the season's calf crop is still on hand. (The actual situation

might be different—*e.g.* some wether lambs might have been retained for fattening, to be sold in October-November.)

The valuation of live stock and equipment requires two adjustments in arriving at total capital requirements. On the one hand the peak investment will not be reached until early August of the following year, when sales of wool, lambs, and draft ewes can be effected. The capital account should thus provide for ten months' future expenditure. This, however, will be partially offset by the sale of the calf crop.

Valuation of Live Stock, Crops, and Equipment

Sheep:		
550 breeding ewes and yearlings at 70s.	£1925	
200 stock ewe lambs at 40s.	400	
12 rams at 150s.	90	
		£2415
Cattle:		
20 cows and in-calf heifers at £55	£1100	
1 bull	100	
16 calves at £25	400	
		1600
Horses:		
2 light carters at £40		80
Poultry		20
Oats, Hay, etc.		300
Implements, Harness, Miscellaneous Stores		450
Ten months' expenditure (five-sixths of £1520)		1267
		£6132
Less sale of 16 calves at £30		480
		£5652

Annual Expenditure

Rent		£160	
Wintering 200 ewe lambs at 25s.		250	
Replacement of rams		40	
Replacement of cows and bull		70	
Wages:			
1 shepherd	£380		
1 general worker	360		
		740	
Fertilizers, lime, seeds, and feeding stuffs		120	
Depreciation on implements and horses		70	
Sheep dip and miscellaneous		70	
			£1520

Annual Income

160 draft ewes at 55s.	£440	
220 wether lambs and 20 ewe lambs at 45s.	540	
Wool: 1800 lb. at 4s. 3d.	382	
16 calves at £30 [1]	480	
Hill cattle subsidy: 20 cows at £5	100	
,, sheep ,, [2]	...	
Ploughing grant: 5 acres at £10	50	
	——	£1992

II. East of Scotland Arable Farm

Throughout Eastern Scotland, up to elevations of the order of 800 ft., ley farming is traditional and all but universal. The general level of cropping intensity—the duration of the ley and the proportion between cash crops and fodder crops—varies according to soil type, rainfall, elevation, and other circumstances. The main live-stock enterprises are beef and mutton production and dairying. In regard to the two former, the emphasis throughout the higher and less fertile regions is on the production of store stock, while in the more fertile and more largely arable farms it is on fattening; under intermediate conditions rearing and fattening are combined. The cereal crops, in order of importance, are oats, barley, and wheat, but on many farms the most important cash crop is potatoes, grown mainly for seed. In the areas of lower rainfall, as far north as Angus, sugar beet is a minor enterprise.

The system exemplified below is one of moderate intensity, and is typical of the lowland parts of the counties of Angus, Perth, and Fife.

Natural and Economic Conditions

The farm lies at an elevation of 150 to 200 ft. with a southerly exposure. Mean annual rainfall is 27 in. The mid-winter climate is similar to that of the Eastern Counties of England (except that the hours of daylight are shorter), but the summer is cooler (some 5° F. lower) and the growing season is some three weeks shorter.

The parent material of the soil is glacial drift, derived mainly from Old Red Sandstone material. The soil is a free-working loam of good depth, with some stones and gravel; it is naturally lime-deficient.

The area is well served with roads and railways, and there is some coastwise traffic with the south. There is a considerable local market for distilling barley and there is a beet-sugar factory. The once large market for milling oats has declined, but the area supplies seed oats for the adjoining upland regions. A considerable amount of farm produce—ware potatoes, fat cattle, and sheep—goes to Glasgow and Northern England, and there is a large export of seed potatoes to England.

[1] It is assumed that the calf subsidy (£7. 10s.) per head is claimed by the buyer.

[2] The hill sheep subsidy is paid only in years when the economic condition of the industry is deemed to necessitate assistance. There was no subsidy in 1954-55.

Allocation of Land

The total acreage is nearly 300, of which 20 are under permanent grass. The traditional rotation is a seven-course, viz.: (1) oats after ley, (2) potatoes, (3) wheat or oats, (4) roots, (5) barley, (6) seeds, and (7) seeds. A common modification is to extend the ley for a third year and to follow with potatoes, thus omitting an oat crop. This applies to about half the land on the farm described. The root " break " is allocated to swedes (20 acres), turnips, kale, and rape (10 acres), and sugar beet (10 acres). Of the 100 acres of temporary grass, about 20 are mown once for hay and a further 20 once for silage.

Conditions for the production of virus-free seed potatoes are not quite ideal; hence half the total potato acreage is planted with material obtained from adjoining high-lying districts.

Tractor, Horse, and Man Power

There are one medium and one light tractor, four horses, and eight full-time workers.

Live Stock

There is an attested breeding herd of non-pedigree Aberdeen-Angus cows producing about thirty calves annually. These are suckled singly by their dams. The calving season is January-March. The produce is sold at a little more than two years old—mostly in March-April at live weights of about 10½ cwt., the quality being choice. About six heifers are retained annually to replenish the breeding herd.

There is a flock of about eighty half-bred (Border Leicester × Cheviot) ewes. Some twenty-five replacements are purchased annually as gimmers (yearlings). The ewes are mated to Suffolk rams to lamb in March, and ordinarily rear about 140 lambs. Single lambs are sold fat off their dams in July; the remainder are finished, mainly on aftermaths, and sold fat by October-November.

Since the farm can carry rather more stock in winter than in summer, some ten to twelve attested store cattle are ordinarily bought in Autumn to be sold fat in May. Again, if there is a surplus of aftermath and rape, some forty to sixty Blackface mountain wether lambs may be bought and sold fat in October-November.

The ewe flock is wintered on grass, with a run over beet tops in Autumn, and silage later, and receive about 2 lb. per head of concentrates from February until there is sufficient growth of pasturage. The breeding cows are wintered on oat straw, roots, and a small allowance of silage, the weaned calves on roots, hay, oats, and a pound or two of linseed or other oil-cake. Fattening cattle have a liberal ration of roots, with oat straw at first and hay later, along with about 4 lb. of concentrates, mainly oats.

Manures and Fertilizers

The general scheme of fertilizer treatment is as set out on page 905, but quantities are varied according to circumstances.

Applications per Acre

	Dung	Ground Lime-stone	Sulphate of Ammonia or Nitro-chalk	Super-phosphate	Muriate of Potash
	tons	cwt.	cwt.	cwt.	cwt.
Oats after ley	...	...	...	...	...
Potatoes after three-year ley	...	...	2	4	2
Potatoes after oats	15	...	3	4	2
Wheat	...	...	2	...	...
Swedes	10	40	1½	5	1
Sugar beet	10	40	2	3	2
Turnips, etc.	...	40	1½	5	1
Cereal after roots (undersown)	...	...	1½	2	...
Hay	...	...	1	2	...
Pasture	...	...	1	...	...

Permanent pasture: lime and phosphate at intervals of four years.
Half the pasture (for early bite) receives about 2 cwt. of nitrogen fertilizer.

Crops

Normal yields are: oats, 28 cwt.; wheat, 22 cwt.; barley, 26 cwt.; early potatoes, 4 tons seed plus 2 tons ware; maincrop potatoes, 5 tons seed plus 3 tons ware with about 1½ tons for stock feed; swedes, 25 tons; sugar-beet, 10 tons; hay, 2½ tons. All straw, hay, and roots and also the bulk of the oats are consumed on the farm.

The cereals are harvested by binder. Potato storage is in conventional clamps (pits).

Some equipment—*e.g.* a dung spreader and a sugar-beet harvester—is shared with neighbours.

Capital

The following is a summarized capital account based on a valuation taken in August (*i.e.* before the commencement of the cereal harvest) when investment is near its peak.

Standing Capital:

4 work horses at £30	£120	
2 tractors (at half new prices)	650	
Field implements (at half new prices)	900	
Oil engine, thresher, and other barn machinery	800	
Carry forward		£2470

	Brought forward	£2,470
Crops and Crop Produce:		
100 acres cereals at £15	£1500	
40 ,, potatoes at £60	2400	
40 ,, roots, etc., at £25	1000	
40 ,, new seeds at £4	160	
50 tons hay at £7	350	
100 ,, silage at £2	200	
		5,610
Live Stock:		
33 cows at £60	£1980	
30 suckling calves at £25	750	
30 yearlings at £50	1500	
80 ewes at £11	880	
80 weaning lambs at £7	560	
		5,670
		£13,750
Miscellaneous:		
Straw, feeding stuffs, and miscellaneous stores on hand, unexhausted manurial residues		800
		£14,550
Less Bank overdraft and accounts outstanding		800
		£13,750

Equivalent to nearly £46 per acre.

Annual Expenditure

Rent at 55s. per acre		£825
Insurance		90
Carriage		150
Labour: 8 full-time men (including overtime, etc.) at £380		3040
Casual: Potato planting, harvesting, dressing, and miscellaneous		460
Seeds:		
Seed potatoes—20 acres at £22	£440	
Roots	30	
Cereals[1]	50	
Grass seeds	120	
		640
Fertilizers and lime (cost *less* subsidies)		780
Purchased feeding stuffs—20 tons at £35		700
Fuel and oil, implement depreciation, fencing, veterinary charges, etc.		1050
Flock replacement (purchases of yearlings *less* sale of cast ewes)		250
Herd replacement (depreciation on bull)		50
		£8035

[1] Most of the seed corn is home-grown.

Annual Income

Crops:

Cereals (yield of marketable grain *less* retention for seed):		
Wheat—40 acres, 780 cwt. at 29s.	£1130	
Barley—20 acres, 480 cwt. at 24s.	576	
Oats—300 cwt. at 25s.	375	
Seed potatoes (*less* retained)—160 tons at £16	2560	
Ware potatoes—100 tons at £8	800	
Sugar beet—100 tons at £6	600	
		£6041

Live Stock:

24 home-bred fat cattle at £70 [1]	£1680	
5 cast cows at £40	200	
Gross profit on 12 store cattle at £15	180	
140 lambs at £7	980	
Gross profit on 40 purchased lambs at £1	40	
Wool—500 lb. at 4s.	100	
		3180

Ploughing Grant:

40 acres at £7. 10s.		300
		£9521

III. Berkshire Corn Farm

The traditional systems of farming light land, in the lower-rainfall areas of Eastern England, were based on cereals—chiefly wheat and barley—as the main cash crops, with folded sheep and yarded cattle as the chief means of utilizing by-products and maintaining soil fertility. The Norfolk four-course was the commonest rotation.

From the eighties of last century such systems became progressively less profitable—at first because of increasing imports of grain and meat from the New Countries and, later, because of the rising wages of the large number of workers required for the cultivation of fodder roots, the folding of sheep, the yard fattening of cattle, and the handling of the farmyard manure. From the thirties onwards, economic conditions improved, the main factors concerned being (1) price guarantees for wheat and sugar beet and (2) the reduction in corn-growing costs—through mechanization, the introduction of improved varieties, and the increasing supplies, at lower prices, of fertilizers.

In the Eastern Counties the main changes in cropping systems have been the replacement of a large part of the fodder-root acreage by sugar beet and the reduction in the area of clover ley to make way for cash crops—notably peas. Where it was practicable to fence the land and to lay on water supplies to the fields, ley farming, with a dairy herd, was successfully combined with cash

[1] Six heifers are retained for herd replacement.

cropping; elsewhere, pigs or poultry might partially replace the folded flock and yarded cattle; but in many cases the system became one of cash cropping with little or no live stock—beet tops being ploughed back and straw either sold or burnt.

On the chalks and other light lands of the South and South-east, where neither sugar beet nor peas became a major crop, two alternatives seemed to offer. The one was a system of corn-and-ley farming, the leys lying for about three years and being followed by two or three successive cereal crops. This plan depended largely for its success on the substitution of leafy and persistent strains of pasture plants for the "commercial" clovers and ryegrasses formerly used. The live-stock enterprise might be either a dairy herd, often run on the outdoor system with a bail, or, alternatively, a flock of "grass" sheep and a stock of store cattle. The other possibility was specialized corn farming—a sequence of three or more cereals followed by a partial or bare fallow. This plan encountered difficulties, viz. the increase of such weeds as wild oat and slender foxtail (which cannot be controlled by selective herbicides) and the build-up of soil-borne diseases and pests, notably "take-all," eyespot, and cereal-root-eelworm. The search for non-cereal cash crops with the necessary low labour requirements had not proved successful at the time of writing. Rape seed had shown some promise, but the demand for the product (by the seed-crushing industry) had not been encouraging.

The following example illustrates the modern organization of what was, up till 1930, a fairly typical sheep-and-corn farm.

Natural Condition

The farm lies at an elevation of 90 to 120 ft. in the Thames Valley and adjoins the river. The major part lies on terraces of valley gravel which have given rise to a variable but rather sticky top soil; winter drainage is made difficult by the small gradients, and some of the land gets water-logged at times when the river level is high. On the other hand, where the subsoil is very gravelly, crops "burn" in periods of summer drought. The gravel is calcareous and the soil reaction is about neutral; hence liming is unnecessary. Lying above the valley gravel, away from the river, is an outcrop of greensand giving rise to a fairly fertile loam. The river-side belt is alluvium, overlying gravel, and is liable to flood. The average rainfall is 28 in.

Economic Situation

The area is well served with roads and railways. There is growing competition from other industries for labour. Some casual labour (women and children) is available for seasonal work. There is a local malting industry. The rental value of the farm is about 50s. per acre.

Fixed Equipment

There is ample barn storage for hay, straw, and corn and ample winter accommodation, in partially covered yards, for cattle. There is a modern grain-drying plant with improvised grain-storage space, hammer mill, etc., and a modern piggery. A large proportion of the land is unfenced and without water supply.

Allocation of Land and Cropping

The total area is nearly 500 acres; the permanent grass consists of 50 acres of riverside meadows and a 10-acre home paddock. An area of about 90 acres is fenced and watered and is under a ley-and-corn system, viz.: (1) wheat; (2) and (3) barley and a three-year ley. The general cropping system on the remaining 360 acres is a six-course, viz.: (1) wheat; (2) barley (undersown); (3) seeds hay (aftermath ploughed in); (4) wheat; (5) barley; (6) potatoes (20 acres), fodder roots (15 acres), and summer fallow (with sometimes an autumn green-manuring crop of mustard, etc.). Wheat may be undersown with trefoil for green manure.

Live Stock

About 60 head of yearling cattle are bought annually—chiefly in autumn or early winter—and are sold fat after about fifteen months' keep, being wintered in yards, summered on the meadows and leys, finished in yards, and sold fat in late winter and spring.

There is a herd of 20 breeding sows, the produce, about 240 in number, being carried to bacon weight. The herd is pedigreed, and some females are sold for breeding.

Field Equipment

This equipment consists of one crawler, one row-crop, and two medium-weight wheeled tractors, combine drill, combine harvester, pick-up baler, and the usual equipment for potatoes. There are no work horses.

Labour

The regular labour force is eight men, of whom two are employed during winter, and one during summer, on live-stock duties. One extra casual worker is employed during cereal harvest, and casual labour is needed for potato picking.

Manuring

Potatoes and mangolds receive all the available dung. Otherwise the humus content of the soil is maintained at a moderate level, on the arable block, by ploughing in aftermaths, occasional green-manuring crops, and the long stubbles. Wheat has 2 cwt. per acre of a low-nitrogen concentrated fertilizer at seed time and a spring top dressing of 2 cwt. sulphate of ammonia. Barley has about 2 cwt. of high-nitrogen concentrate. Seed-time dressings are normally applied by combine drill. Potatoes have 9 cwt., swedes 4 cwt., and seeds hay 2½ cwt. of appropriate compounds.

Crop Yields

Yields vary widely from year to year, according to the incidence of winter waterlogging (which may result in late planting) and early-summer drought. Long-term averages are: wheat, 18 cwt.; barley, 20 cwt.; potatoes, 8 tons; mangolds, 20 tons; swedes, 14 tons; and seeds hay, 30 cwt.

Capital

The following is based on a Michaelmas (30th September) valuation, and it is assumed that the whole of the wheat and all barley of malting quality has been sold. If this were the position, a considerable cash balance should be in hand, since expenditure will largely exceed receipts during the period until the following year's corn crops are marketed.

Field Equipment [1] (at half new prices):		
4 tractors	£1450	
Combine harvester	600	
Pick-up baler	300	
Ploughs, cultivators, drill manure distributors, trailers, potato equipment	900	
		£3,250
Live Stock:		
60 two-year-old cattle (forward stores) at £65	£3900	
20 breeding sows at £30	600	
1 boar	60	
200 other pigs at £9	1800	
		6,360
Crop Produce and Growing Crops:		
300 tons straw at £2	£600	
100 ,, hay at £7	700	
20 acres potatoes at £60	1200	
15 ,, roots at £30	450	
70 ,, maiden seeds at £3	210	
40 tons feed barley and tail corn at £25	1000	
Seed wheat	450	
		4,610
Miscellaneous:		
Stores, unexhausted manurial values	£900	
Cash in hand	2500	
		3,400
		£17,620

Equivalent to about £35 per acre.

Annual Expenditure

Rent (50s. per acre)	£1250	
Labour—8 men at £380	3040	
Casual labour	150	
Fertilizers (cost *less* subsidy)	1450	
Feeding stuffs (in addition to 40 tons barley and tail corn)	1400	
Fuel, oil, and electricity	800	
Depreciation and repairs to equipment	1000	
Insurance, carriage, consumable stores, etc.	550	
		£9,640

[1] The grain-dryer, valued at £400 or £500, is a landlord's fixture.

Annual Income

Wheat—115 tons at £28	£3220	
Barley—110 tons at £28	3080	
Potatoes—120 tons at £10	1200	
Pigs:		
150 baconers at £20	3000	
10 breeding gilts at £25	250	
Gross profit on 60 feeding cattle at £25	1500	
		£12,250

IV. Cheshire Dairy Farm

The holding here described lies in the southern part of the Cheshire plain. Specialization in dairying, chiefly cheese production, began very early, the product being sent to London by sea before the days of canals or railways. Specialization has since increased, but the great bulk of the milk is now sold on the liquid market and there is very little farmhouse cheese-making. Coincident with the change in milk disposal there has been a marked trend from summer to year-round milk production. Up till 1939, however, the general practice was to use pasturage and home-grown bulky foods in conjunction with purchased concentrates. During the Second World War intensified grassland management set free land for the production of cereals, beans, etc., and outputs of milk were well maintained. Since the war there has been some decline in tillage and more dependence on purchased feeding stuffs, but the output of milk has risen.

Natural Conditions

The farm lies at an elevation of about 150 ft. The situation is sheltered and the configuration flat. Annual rainfall is about 30 in. The winter is fairly mild, but the land lies rather wet, so that stock must be housed in winter to avoid damage to swards. The geological formation is Keuper Marl with some boulder clay, giving rise to fertile clay loam or clay soils. The lime status varies from good to moderate.

Economic Situation

Industrial Merseyside to the north and the Pottery district to the south are each about thirty miles distant. The area is well served with roads, and most farm requisites can be delivered from works or mills by road. Electric power is generally available.

Allocation of Land and Cropping

The total area is 210 acres. Some 60 acres of the lightest land is old arable, farmed on a six-course rotation, viz.: (1) oats; (2) fodder roots and kale; (3) wheat or oats (undersown); and (4) to (6) a three-year ley, commonly mown for hay or silage in both the first and second seasons (the after-growth being grazed) and grazed during the whole of the third. Thirty acres of heavy and rather poorly drained land are permanent meadow, the aftermaths being grazed by dry cows and young stock.

Sixty acres more is under a ley-and-corn rotation, ordinarily (1) wheat, (2) oats and beans, and (3) to (6) ley which is commonly mown for silage in its first year, being too "tender" to carry cattle. The remaining 60 acres are permanent pasture.

Fixed Equipment

There is a cowshed for seventy-five, with calving boxes, calf house, and yards for older dry stock. The milking machine and hammer mill are electrically driven. There is adequate Dutch-barn space for hay and corn.

Manures and Fertilizers

The permanent pasture has a dressing of about 5 cwt. basic slag at intervals of four years. Permanent meadows are dunged at intervals of four years and receive about 3 cwt. per acre of complete compound in the intervening years. Root crops have about 15 tons per acre of dung, with 4 to 6 cwt. of appropriate compound fertilizer. Wheat following ley receives only a light spring application of nitrogen. Second corn crops and "seeds" hay have 3 cwt. of a nitrogen-phosphate compound. About 20 acres of pasture is dressed, for "early bite" with nitrogen. Average usage of lime is about 20 tons per annum.

Crop Yields

Meadow hay, 1½ tons; seeds hay, 2½ tons; oats, 22 cwt.; wheat, 26 cwt.; mangolds, 40 tons; kale and swedes, 20 tons.

Live Stock

The attested dairy herd comprises eighty grade Friesian cows and about forty-five "followers." The remaining live stock consist of three breeding sows (the produce being sold as baconers) and about 100 head of poultry.

Maiden heifers and some of the poorer cows are artificially inseminated to produce Aberdeen-Angus cross-calves. These, and the male Friesian calves, are sold at the age of a week or two.

Labour

The regular labour force is five men and a lad. Some casual labour may be employed at hay-time.

Capital

The following estimate is based on a Lady Day (25th March) valuation:—

Equipment (at half new prices):

2 tractors, tillage implements, drills, binder, etc. .	£1000	
Barn machinery, poultry houses, etc.	180	
Dairy equipment, (milking machine, sterilizer, cooler, etc.)	350	
Carry forward		£1530

	Brought forward	£1,530
Cattle:		
75 cows at £70	£5250	
45 other cattle at £40	1800	
Bull	150	
		7,200
Other Live Stock:		
3 sows at £25	£75	
30 other pigs at £10	300	
100 head poultry at £1	100	
		475
Stocks and Tenant Right:		
Hay, straw, and feeding stuffs; growing crops and maiden seeds; residual manurial values, etc.		1,200
		£10,405

Equivalent to about £50 per acre.

Annual Expenditure

Rent—£4 per acre		£840
Labour:		
3 stockmen at £450	£1350	
2 other men at £380	760	
1 lad at £200	200	
Casual	80	
		2390
Feeding stuffs—55 tons at £35		1925
Seeds		250
Fertilizers and lime (*less* subsidies)		330
Replacement of bull		50
Tractor, fuel and oil, electricity, repairs and depreciation of equipment, veterinary charges, consumable stores, carriage, and insurance		1100
		£6885

Annual Income

50,000 gallons milk at 3s.	£7500
40 calves at £4	160
36 bacon pigs at £16	576
20 old, barren, and casualty cows at £30	600
Eggs	110
Wheat (production *less* usage for poultry, etc.)	200
	£9146

III.—ADJUSTMENT OF THE FARMING SYSTEM TO CHANGING CONDITIONS

No rigid farming scheme can be expected to produce maximum profit over any long period of time, and since neither economic changes nor technical developments can be predicted with assurance, flexibility is an important objective in farm planning.

This has particular importance in relation to farm buildings and other fixed equipment. In the past, farm buildings have often been sited and planned with much too little regard to possible changes in use; there are many old horse stables that cannot be satisfactorily converted into cowsheds, piggeries, grain stores, or tractor sheds; many old cattle yards that cannot readily be adapted to permit of mechanised foddering or dung-handling; implement sheds so sited that they cannot be enlarged to accommodate the growing range of equipment, particularly such large machines as the combine harvester or the tractor drill. Again, there are many examples of massive stone-walled buildings that have remained structurally sound long after they have become obsolete.

In general, then, buildings should be of such dimensions as will permit of a variety of uses. Much thought has been given to this object, and there is now a supply of mass-produced pillars, roof trusses, etc., in a limited number of standard sizes, which provide for a large number of uses. Where highly specialized buildings are in question, it may be true economy to build in relatively cheap materials with a view to a relatively short life.

Again, many farms have been laid out and divided up with stone wall or hedge-and-ditch fencing, on the assumption that an existing cropping plan, and the existing types of field implements, would long continue to be appropriate. In many districts fields are too small and too irregular in shape to permit of the full and economic use of tractors and tractor-drawn tools. Movable or temporary fences have many advantages.

The more important kinds of adjustments that may fall to be considered are set out below, with examples.

1. **Substitution of One Enterprise by Another.**—Perhaps the commonest incentive to substitution is a change, or an expectation of change, in the relative profitability of an existing enterprise and a practicable alternative. But other considerations may arise—*e.g.*, a change in the supply of labour, a change in

the farmer's capital resources, or some major technological development.

During the past half-century many farmers were led to the view that milk offered better prospects than beef production. Population was increasing, and consumption per head was rising as the nutritive value of milk became more widely recognized, while the liquid milk market was not open to overseas competition. Again, there was increasing scope for higher yields, by reason of progressively better control over bovine disease and advances in breeding, feeding, and management. On the other hand, with developments of meat preservation—particularly freezing and chilling—and with the opening up of the grasslands of the new countries, there was reason to expect increasing pressure of imports of meat.

The change-over from beef to milk involved additional capital investment (in buildings and dairy equipment), the training of workers in milk production, and the acquisition by the farmer himself of new knowledge and skills. But, in general, the change did, in fact, result in improved profitability.

At the time of writing it appeared that there might be a balance of advantage in a reverse change. Consumption of liquid milk had ceased to increase and yields of milk, per cow, were rising; world supplies of dairy produce—butter, cheese, and evaporated milk—were ample, and costs of production of those commodities, for various reasons including climatic conditions, were lower in certain overseas countries than in Britain. At the same time, the production of beef was tending to give way, in certain overseas countries, to other enterprises, while the growth of population in many of the meat-exporting countries was reducing the quantities of beef available for export. But the balance of argument for the change (from milk to beef) varied as between one farm and another. The small farmer would suffer a decline in gross income, and the family farmer might find it difficult to secure full employment for his available labour force, while the large-scale farmer might be able to reduce his wage bill and give more time and thought to his other enterprises.

2. **A Change in Form of an Individual Enterprise.**—An existing system of producing some particular commodity may be outmoded by some step of technical progress, by a change in economic conditions, or by some combination of these and other circumstances.

Towards the end of last century the close-folding system of sheep husbandry, once typical under light-land arable conditions in the south-eastern half of England, became uneconomic, partly by reason of the fall in cereal prices, partly because increasing supplies of fertilizers, at lower prices, provided a cheaper means of maintaining soil fertility, partly because sugar beet gave a better return than folded roots, and partly because the labour cost of folding (in relation to prices of mutton and wool) rose to a level that could hardly be borne. The alternatives open to the farmer were to turn over from the folding system to leys and grass sheep husbandry (which involved capital expenditure on fencing) or to abandon the sheep enterprise altogether. The latter alternative was commonly selected in the Eastern Counties, while in the south the former was often preferred.

Again, in recent times the colony-house system of poultry keeping has in many cases been replaced by one or other of the "intensive" systems—the deep-litter house, the laying battery, or the hen yard. The one incentive has been a reduction in labour cost and the other a more favourable pattern of seasonal production—a higher proportion of winter eggs. The change has been facilitated by the development of electricity supplies in rural areas.

Recent times have seen two rather widespread changes in the organisation of milk production. The "milk-and-feed" system, under which herd replacement was by the purchase of mature cows at or near to calving and the cattle were sold as they dried off, suffered over a period from the circumstance that the farmer could hardly qualify for the premium offered for tuberculin-tested milk. Hence many producers proceeded to build up self-contained herds, rearing all necessary replacement stock. Recently, however, there has been a great increase in the supply of tuberculin-tested heifers, and many small producers have reverted to their former practice on the ground that milk production from mature cattle yielded higher profits and provided fuller employment than the combination of milking and rearing.

Other milk producers, long accustomed to purchase the bulk of their concentrated feeding stuffs (because these could be bought at prices below the farmer's own cost of production) and, for the rest, to depend on ordinary pasturage and hay, were obliged, by the war-time scarcity of feeding stuffs, to intensify their grassland management and to set aside land for the production of cereals,

kale, etc. At the time of writing, imported concentrates were again in ample supply at relatively low prices, and some farmers, especially in areas unfavourable to arable farming, were reverting to their former practice. In many cases, however, the intensification of grassland management and the improvement in conservation methods had proved profitable in themselves, and the choice was between continuing the war-time system or expanding milk production with purchased and home-grown feed.

3. **Changes in the Number or in the Balance of Enterprises.**—The classical arguments for a high degree of diversification—the combination of many enterprises—are the spreading of economic risks, the reduction of biological risks (soil-borne disease, animal disease), efficient utilization of cash-crop by-products (straw, sugar-beet tops, tail corn, etc.) by means of livestock, the maintenance of soil fertility, and the provision of productive work, throughout the year, for the regular workers.

The force of these arguments has, however, tended to decline. Under the existing conditions of guaranteed prices and assured markets for many commodities price risks have been greatly reduced. Measures other than the rotation of crops and mixed stocking are available for the control of diseases and pests; fertilizers are a cheaper source of plant nutrients than the residues of imported concentrates; and the mechanization of cereal production and hay-making has relieved the pressure of work at hay-time and harvest.

The positive arguments for increased specialization—*i.e.* for a reduction in the number of enterprises comprising the traditional system—are firstly that the individual worker will commonly be more efficient as the variety of his tasks is reduced; secondly, that specialized equipment (the combine harvester, pick-up hay baler, or beet harvester) can be expected to be economic only if used up to something approaching full capacity; and thirdly, that, with the accelerating rate of technical progress, it becomes increasingly difficult for the farmer himself to maintain a high level of efficiency in the management of each and all of a large number of enterprises.

Despite these broad arguments for simplification of the farm system, individual circumstances may and often do call for an addition to the existing enterprises. The commonest objective is perhaps that of securing full employment, under changed

conditions, for an existing number of workers. On the larger farms, employing four or more workers, the benefit from measures to increase the productivity of labour may be realised either by a change in the balance of enterprises, by raising the general level of intensity of production, or by dispensing with a worker. But the same choice is not open to those farmers (the great majority) who employ three or fewer workers.

Thus if with a two-man dairy unit we install a milking machine and modern milk-handling equipment, and provide improved facilities for feeding and cleansing, we may be able to run the herd with one full-time and one half-time worker, and it may be impracticable to increase the size of the dairy herd by the amount necessary to provide the desirable full employment. In such a case the appropriate solution may be to set up a "half-man" pig or poultry unit as an addition to the existing enterprises. Again, many family farms are too small in acreage to provide either full employment or an adequate standard of living under the traditional farming system. In such case the most promising approach may be to add an enterprise that will use no considerable acreage of land—a pig or poultry unit or a glasshouse.

4. **The Level of Intensity.**—Apart from the question of the make-up of the farming business, the enterprises comprising it and the balance between them, the farmer is concerned to get, in each enterprise, the optimum level of intensity—*i.e.* with regard to each element of input (labour, fertilizers, feeding stuffs, etc.) the level that will give the maximum profit.

Although the distinction is never quite clear-cut it is possible to divide the inputs for the production of a given commodity into *fixed* and *variable* costs. For example, in the production of potatoes the land must be worked to a tilth, seed must be bought, and the crop must be harvested. There are only minor savings to be made by scamping the tillage, by planting less than the standard quantity of seed, or in harvesting a 5-ton as compared to a 10-ton crop. On the other hand, manures and fertilizers may be applied in widely varying amounts, and it is important to find the optimum level, *i.e.* the application that will achieve the highest level of profit.

The response of crops to manures and fertilizers is subject to the "law of diminishing returns"—*i.e.* each successive addition to the dressing produces a lower response than the preceding one. The point may be illustrated by the response of a particular

variety of potatoes to farmyard manure at varying levels, and the following table sets out the data for a particular case :—

Plot No.	Dung, Tons per Acre	Yield, Tons per Acre	Yield Increment (Tons per Acre) for each Successive Addition
1	0	4·6	...
2	4	5·9	1·3
3	8	6·7	0·8
4	12	7·4	0·7
5	16	7·8	0·4
6	20	8·0	0·2

Assuming a constant price (or cost) per ton for dung, the most profitable application will depend on the price realized for the crop. In the following table the value of farmyard manure is put at 30s. per ton and a calculation of profitability, for each level of application, is made for three levels of potato prices, viz. £6, £9, and £12 per ton :—

Plot No.	Cost of Dung, £	Yield, Tons per Acre	Total Value of Crop per Ton at			Value of Crop, less Cost of Dung		
			£6	£9	£12	£6	£9	£12
1	Nil	4·6	27·6	41·4	55·2	27·6	41·4	55·2
2	6	5·9	35·4	53·1	70·8	29·4	47·1	64·8
3	12	6·7	40·2	60·3	80·4	28·2	48·3	68·4
4	18	7·4	44·4	66·6	88·8	26·4	48·6	70·8
5	24	7·8	46·8	70·2	93·6	22·8	46·2	69·6
6	30	8·0	48·0	72·0	96·0	18·0	42·0	66·0

It thus appears that the most profitable dressings of dung were about 4 tons, 10 tons, and 12 to 13 tons respectively. In no case was the full dressing as profitable as something less.

The figures below illustrate the application of the law of

Rate of Application, Cwt. per Acre	Yield, Cwt. per Acre	Added Yield, Cwt. per Acre	Value of Added Yield	Cost of Added Fertilizer	Net Value of Additional Yield
			s. d.	s. d.	s. d.
Nil	21·0	...	...	...	...
1	24·0	3·0	88 6	13 5	75 1
2	25·8	1·8	53 1	13 5	39 8
3	26·8	1·0	29 6	13 5	16 1
4	27·5	0·7	20 8	13 5	7 3
5	27·9	0·4	11 10	13 5	−1 7

diminishing returns to the application of sulphate of ammonia to wheat, in the absence of dung, on good land. The calculation is made at prices ruling in 1952-53, viz. 13s. 5d. per cwt. for sulphate of ammonia and 29s. 6d. per cwt. for wheat.

It thus appears that on average the most profitable dressing under the conditions prevailing was 4 cwt. per acre. The responses, however, varied from one trial to another, being influenced by such factors as soil type, climatic conditions, and the variety of wheat grown. Under certain soil-climate-variety combinations the risk of lodging, at the higher levels of nitrogen, would be a material consideration in deciding the level of nitrogen dressing.

The optimum level of the variable inputs (*e.g.* as fertilizers) depends on the relationship between the variable and the fixed or near-fixed costs. But it also depends on the degree of technical skill of the farmer. The point may be illustrated by the relationship of milk yield, per cow, to profitability. The potential yield of a cow depends on the skill of the farmer in such matters as breeding and rearing. And actual yields depend on the farmer's efficiency in controlling disease, in compounding rations, etc., and on that of the cowman in day-to-day operations, including milking. The substantially fixed costs—provision and maintenance of buildings, the wage cost of milking, milk handling and cleansing, and providing the maintenance ration—constitute a large proportion of total costs.

The "law of diminishing returns" applies, but only in small degree, to the output of milk—for instance, the production of the fifth gallon per day costs somewhat more, in nutrients, than that of the third. The overall result is that, within wide limits, high yield makes for low cost per gallon. Moreover, the larger profit per gallon, on the higher yield, ordinarily results in a marked increase, with increasing yield, in the margin of profit per cow. The relationship between yield and profit margin may be illustrated by the data (shown on page 921) derived from the National Milk Cost Investigation, 1949-50.

In certain enterprises it may, however, be possible, by a change of system, to achieve a major reduction in "fixed" costs. In the case of milk production such a saving can be achieved under the "outdoor" or "bail" system. The capital cost of the milking bail is small by comparison with that of a set of permanent buildings, while there is a reduction in labour

costs of cleaning and manure carting. Again, bulky materials such as hay and silage can often be consumed in the fields where they have been grown, thus eliminating transport costs. Hence

	Yield Group						
	A	B	C	D	E	F	G
Mean yield (gallons per cow)	407·0	514·0	600·0	687·0	771·0	861·0	1035·0
Labour (hours per cow)	148·0	129·0	139·0	139·0	150·0	161·0	184·0
Food cost per cow (£)	26·4	30·3	34·0	38·1	42·9	47·9	57·9
Net total cost per cow (£)	48·3	54·9	58·9	64·3	70·4	76·7	89·2
Returns per cow (£)	55·6	71·1	82·3	95·8	109·2	122·4	148·4
Farm cost per gallon (pence)	28·5	25·6	23·6	22·5	21·9	21·4	20·7
Margin per gallon (pence)	4·3	7·6	9·4	11·0	12·1	12·7	13·7
Margin per cow (£)	7·3	16·2	23·4	31·5	38·8	45·7	59·2

it can happen that a yield per cow of 700 or 800 gals. from a "bail" herd may leave as large a margin per cow as one of 1000 gals. under the traditional cowshed system. Soil and climatic conditions, however, may preclude the former.

CHAPTER IV

MEASURES OF ECONOMIC EFFICIENCY—FARM BUDGETING

SOME judgment of farming efficiency can of course be formed on such evidence as the appearance of crops and grass, the apparent quality of livestock, and the timeliness of seasonal operations; but if a proper assessment is to be made, such general impressions must be supplemented by information about input-output relationships, and farm economists have devised a number of standards by which business efficiency can be measured.

In many manufacturing industries the commonest measure of efficiency is the cost of production of the finished article, and at one time it was thought by many that cost accounting could serve the same purpose in agriculture. It is indeed possible, to some extent, to allocate inputs—labour, fertilizers, feeding stuffs, etc.—between the various enterprises that constitute the business, and to put values upon such by-products as straw and farmyard manure; but the basis for the valuation of by-products is largely a matter of guesswork. Again, labour is ordinarily charged at flat rates as between one task and another, whereas in practice the return per man-hour varies widely as between one task and another. In any case the determination of enterprise costs necessitates a very elaborate system of accounting including, for example, a detailed time-sheet for each man and a separate record for each field or group of livestock.

The degree of difficulty varies as between one enterprise and another. It is, for instance, small in the case of a pig or poultry unit run mainly on purchased feeding stuffs. By contrast, the cost of the winter-fattening of cattle can be arrived at only by making a series of assumptions about the value of unsaleable commodities such as roots, straw, and farmyard manure. Finally, the production cost of a particular commodity may vary widely from year to year by reason of differences in weather conditions, and it is difficult to make proper allowance in such cases.

Cost accounting is indeed applied by farm economists to considerable numbers of entire farms, as well as to individual

enterprises such as milk production or potato growing. The chief use of such determinations is in identifying the factors affecting costs. Three examples are set out below.

I.—Costs and Returns per Acre of Barley on 1686 Acres on Twenty-three Farms in Southern England, 1952

	£	s.	d.
Costs:			
Preparatory cultivations	£1	17	8
Manures	3	9	7
Seed	3	3	7
Drilling, harrowing, rolling seed	0	12	1
Other post-drilling operations	0	5	4
Total to harvesting	£9	8	3
Harvesting and post-harvesting	4	7	3
Rent	1	8	0
Overheads	3	15	10
Gross costs	£18	19	4
+ Residual values brought forward	0	1	0
— ,, ,, carried ,,	1	12	2
Net costs	£17	8	2
Returns:			
Grain	£25	12	0
Straw and grazing	1	5	9
Total	£26	17	9
Surplus	£9	9	7
Yield	18·3 cwt.		
Average price received per cwt.	£1	8	0

As might be expected, the variation in cost *per acre* as between farm and farm was relatively small—the reason being that so-called fixed costs, *e.g.* seed, tillage, and harvesting, constituted a large proportion of the whole. Profitability therefore depended mainly on yield per acre and quality of the grain; and yield was markedly influenced by the level of fertiliser usage. The relationship is shown below:—

Yield Group	Average Yield	Returns	Net Costs	Surplus	Expenditure on Fertilisers
Per Acre	Cwt.	£	£	£	£
Over 25 cwt.	28·3	41·2	18·2	23·0	3·9
20 to 25 cwt.	21·7	31·8	17·7	14·1	3·7
15 ,, 20 ,,	18·0	25·0	17·0	8·0	3·4
Less than 15 cwt.	12·3	16·4	15·3	1·1	2·1

II.—Cost and Returns from Growing Potatoes on 396 Acres of the Nottinghamshire Sands, 1952 Harvest

	Per Acre £ s. d.	Per Cent.
Cost of Work:		
Manual labour	15 19 9	27·2
Horse labour	0 4 3	0·3
Tractor labour	3 19 5	6·8
Contract machine labour	0 10 7	0·9
Total operation cost	20 14 0	35·2
Other Costs:		
Rent	1 4 7	2·1
Seed	17 5 3	29·4
Manures (including lime and farmyard manure)	13 19 3	23·7
Miscellaneous costs*	0 15 2	1·3
Machinery depreciation and repairs	2 11 7	4·4
Overheads†	4 6 10	7·4
Total other costs	40 2 8	68·3
Net manurial residues	−2 1 2	−3·5
Total net other costs	38 1 6	64·8
Total costs	58 15 6	100·0
,, returns	80 1 6	...
Net profit	21 6 0	...
Average yield (tons)	7·6	
Cost per ton	£7 14 8	
Return per ton	10 10 9	

* Includes spraying, sack-hire, straw for clamping, etc.
† Includes a charge for hedging, ditching, upkeep of buildings, and other expenses.

Some indication of the factors affecting profitability may be obtained from the comparison on page 925 of the figures for the three most profitable and the three least profitable of the fields costed.

Clearly in this case also profitability is closely related to yield, the one group showing a range from 10½ to 12½ tons and the other from 2½ to 4½ tons. The evidence on the factors affecting yield is, however, very limited. Field E, indeed, was under-manured, and the quality of the seed may have been poor. In the case of field D there appears to have been false economy in

Three Most Profitable Fields

Size of Field	Net Profit per Acre	Yield per Acre	Price per Ton	Artificial Fertilizer Expenditure	Comments on Fertilizers	Seed Costs	Comments on Seed	Power and Labour Costs per Acre
Acres	£	Tons	£	£		£		£
A. 6	78·7	12	12·5	9·3	11 cwt. compound fertilizer No farmyard manure Previous crop: Oats	24·9	23 cwt. Scotch Majestic	31·7
B. 16	69·7	12	11·1	20·3	16 cwt. compound fertilizer No farmyard manure Previous crop: Barley	25·4	24 cwt. Scotch Majestic	21·2
C. 6	38·9	10	10·5	11·5	12 cwt. compound fertilizer 10 tons of farmyard manure Previous crop: Oats	13·1	17 cwt. once grown Majestic	31·0

Three Least Profitable Fields

Size of Field	Net Loss per Acre	Yield per Acre	Price per Ton	Artificial Fertilizer Expenditure	Comments on Fertilizers	Seed Costs	Comments on Seed	Power and Labour Costs per Acre
Acres	£	Tons	£	£		£		£
D. 8	−25·7	2·5	7·4	13·0	10 cwt. compound fertilizer 2 cwt. muriate of potash 10 tons of farmyard manure Previous crop: Barley	6·6	10 cwt. once grown Majestic	17·6
E. 5	−7·4	4·5	8·0	4·9	4 cwt. compound fertilizer No farmyard manure Previous crop: Wheat	13·2	A mixture of varieties mostly once grown	17·6
F. 7	−1·9	4·5	10·1	10·9	13 cwt. compound fertilizer No farmyard manure Previous crop: Rye	16·5	16 cwt. Arran Banner Scotch Seed	19·1

regard to seed and (judging from the expenditure on power and labour) the cultivations may have been scamped. But other information on such matters as tillage, time of planting, weed infestation, and blight control would be required for a proper interpretation of the financial data.

III. Costs of Commercial Egg Production

The following table shows the average cost of egg production in 1949-50 for thirteen poultry flocks comprising some seven thousand birds :—

Costs per Hen per Year and per Dozen Eggs

Costs and Returns	Per Hen	Per Cent.	Per Dozen Eggs
	£ s. d.		£ s. d.
Foods :			
Purchased	1 4 9	47·6	0 1 10¾
Home grown	0 3 3½	6·3	0 0 3
Gross food costs	1 8 0½	53·9	0 2 1¾
Less manurial values	0 1 4½	2·6	0 0 1¼
Net food costs	1 6 8	51·3	0 2 0½
Labour :			
Hired	0 5 3½	10·2	0 0 5¼
Farmer, wife, and family	0 2 7¼	5·0	0 0 2¼
Total labour	0 7 10¾	15·2	0 0 7½
Total food and labour	1 14 6¾	66·5	0 2 8
Other Expenses :			
Rent	0 0 1	...	...
Rates	0 0 0¼	...	...
Insurance	0 0 2¼	...	...
Fuel, light, power	0 0 2¼	...	...
Equipment repairs	0 0 5¼	...	...
Horse work	0 0 0¼	...	...
Tractor work	0 0 4	...	...
Sundry expenses	0 0 1¾	...	...
Share of overheads	0 0 11¼	...	...
Total other expenses	0 2 4¼	4·5	0 0 2¼
Equipment depreciation	0 3 2½	6·2	0 0 3
Flock depreciation	0 11 10½	22·8	0 0 10¾
Total costs	2 12 0	100·0	0 4 0
Receipts	2 16 7	...	0 4 4
Net profit	0 4 7	...	0 0 4

It will be noted that food costs constituted about 51 per cent., flock depreciation nearly 23 per cent., and labour fully 15 per cent., leaving only 11 per cent. for all other items. The range of egg prices during the year in question was from 3s. 9d. in the period February to August, to 5s. 9d. in the period from mid-October to mid-January.

Some indication of the factors affecting profitability can be derived from a comparison of the figures for the nine flocks which showed a profit with the four which showed losses.

Costs and Returns per Hen	Flocks showing Profits, Nine Flocks, 3688 Hens	Flocks showing Losses, Four Flocks, 3283 Hens
	£ s. d.	£ s. d.
Foods:		
Purchased	1 1 2	1 8 9
Home grown	0 6 1	0 0 2
	1 7 3	1 8 11
Less, residual manurial values	0 1 4	0 1 5
Total foods	1 5 11	1 7 6
,, labour	0 9 1	0 6 7
Total food and labour	1 15 0	1 14 1
Other expenses	0 3 2	0 1 5
Equipment depreciation	0 3 7	0 2 9
Flock depreciation	0 10 5	0 15 1
Total expenses	0 17 2	0 19 3
Total cost	2 12 2	2 13 4
Receipts	3 5 9	2 7 11
Net profit	0 13 7	...
,, loss	...	0 5 5
General Data:		
Average flock size	410 hens	820 hens
,, yield per hen	181 eggs	134 eggs
Pullets in initial flock	78 per cent.	76 per cent.
Mortality	17 ,, ,,	27 ,, ,,
Capital equipment per layer	£1 12 0	£1 5 0
Selling price per dozen eggs	0 4 3	0 4 3
Food per day:		
Concentrate	5·3 oz.	4·8 oz.
Other	0·5 ,,	0·8 ,,
	5·8 ,,	5·6 ,,

From the figures in the table, and from other data which has not been included, the following conclusions were drawn by the investigator :—

1. The profitable flocks, by comparison with those which were run at a loss, were characterized by higher egg yields, lower flock depreciation, and lower food costs.

2. The profitable flocks produced a higher proportion of winter eggs than the unprofitable group.

3. Flock depreciation is not increased by heavy culling, since heavy culling results in low mortality.

4. Hen batteries produced higher egg yields than open-range arks, but had correspondingly higher food costs and higher charges for capital depreciation.

The most useful approach to the assessment of efficiency of management on a particular farm is by comparing the readily available data with standards derived from fully-costed farms of similar type in the same region. The available data are of two kinds, viz. physical and financial. The former include such things as the yields of crops, the stock-carrying capacity of grass, milk yield per cow, etc. In some cases figures will be available for the overall food consumption as well as of the production of the several livestock groups (milking cattle, pigs, poultry), and in some cases there may be records of pig litter numbers and weaning weights, and of age as well as slaughter weights. It is very desirable that such records should be kept. The financial information required can usually be obtained from the ordinary form of farm account.

Farm economists classify their fully-costed holdings on the combined basis of size and of the relative importance of the constituent enterprises—*e.g.* " cropping with substantial dairying, 150 to 300 acres," " intensive arable, 50 to 100 acres," " cattle and sheep rearing, over 200 acres," " hill sheep, over 500 ewes." The physical and financial data of the costed farms are used to provide standards for assessing the efficiency of the particular holding.

The chief measure of overall efficiency is, of course, profit, the total income that the holding yields. Profit is the balance between receipts (including home produce consumed by the farm family) and expenditure, with a correction for the difference between opening and closing valuations. In some cases—

particularly the smaller farm—it may be well to divide the income into two parts, viz. (*a*) the "notional wages" earned by the farmer and any member of his family in operational work, and (*b*) the remainder, which represents interest on capital plus the reward for management. The latter part is described as "Management and Investment Income." There is nothing to be gained by splitting the last into interest on capital, a notional salary for management and a balance of "profit." The profit is commonly expressed on a per-acre basis, but this is inappropriate in certain cases, *e.g.* mountain sheep farms or glasshouse holdings.

Let us suppose that a farm of 180 acres in the East Midlands of the type "dairying with substantial cash cropping" has shown, in the year 1952-53, an income of £630 (£3. 10s. per acre), and that it appears to have no substantial advantages or disadvantages over the average of its type. In the year in question the overall average net farm income for the group to which the holding belongs was £9. 10s. per acre, while the most successful farmers (one in four) achieved a figure of £12. 10s. per acre. It is clear that the results on the particular farm fell far below the norm, and very far short of what appears to have been possible.

The first step in the analysis of the problem is to determine how far the failure is to be explained by abnormally low production and how far by excessive expenditure. It is thus necessary to have measures of output and input.

Gross Output—total sales corrected for the difference between opening and closing values—is not, in itself, a good measure of overall production. For instance, if a farmer buys twenty store cattle in spring, at £60 per head, spends £2 per head on feeding stuffs, and sells the cattle at £80 per head, the measure of his output is not £1600 but £1600 minus (£1200 + £40), *i.e.* £360. Again, if a potato grower spends £20 per acre on seed and the crop realises £80 per acre, the output should be reckoned at £60.

Purchases of livestock, of feeding stuffs, and of seeds are the most important variables as between farm and farm, and hence the measure generally applied—commonly called *Net Output*—is arrived at by deducting from total sales (corrected for valuation differences) the total expenditure on livestock, feeding stuffs, and seeds.

In a particular area the figures for farms of 100 to 150 acres were :—

Farm Type	Gross Output per Acre	Net Output per Acre
Mainly dairying . . .	£38	£24
Cash cropping . . .	51	41
Cropping with livestock (other than dairying) . . .	33	24

It will be seen that there is considerable difference in the ratio between the gross and net figures as between one farming type and another.

Since the wage bill is by much the largest item of expenditure on a majority of farms it is clear that some measure of output per man is necessary to the assessment of efficiency. Since, however, wage rates vary according to the age of the worker and the amount of overtime work, and since casual labour may be employed, it is sounder in principle (and, incidentally, easier in practice) to make the calculation in terms of wages, or of work units (notional man days) per 100 acres. Even so, as might be expected, there is no regular relationship between such a figure and profitability. One particular area gave the following figures (work units per 100 acres) in a particular year :—

Farm Type	Group Average	Six Most Profitable Farms in Group
Dairying—under 150 acres . . .	1052	970
,, over 150 ,, . . .	847	909
Cash cropping—under 150 acres . .	940	940
,, ,, over 150 ,, . .	731	758
Cropping with livestock—under 150 acres	665	683
,, ,, ,, over 150 ,,	693	750

In particular cases this kind of calculation may show that a farm is grossly over- or under-manned. But a much more useful figure, which is no more difficult to determine, is *net*

output per £100 paid in wages, net output being as defined on page 929.

It would obviously be useful if we could express net output in relation to the third major factor in production—viz. the tenant's capital (including loan capital) invested in the farm business. In some cases *net output per £1000 capital* has been used in the assessment of efficiency. The difficulty is the practical one that the figures for capital, as shown in the accounts of the costed farms, may bear little relation to the amount actually invested. For example, dairy herds and other "regular breeding stocks" are commonly valued on the "herd basis," *i.e.* at figures that take no account either of changes in actual prices or of progressive improvement in quality. Again, depreciation of plant and machinery is ordinarily calculated at the maximum rates allowable by the Inland Revenue authorities, and many items in annual valuations—*e.g.* unexhausted manurial values—are often entered in annual accounts at nominal figures. In short, net output per unit of capital, whether or not it could be estimated in a particular case, would be of little value on account of the lack of good data from the costed farms.

If a particular farm (as judged by comparison with others of similar type) is showing an unsatisfactory profit, the first broad question is how much of the explanation lies in excessive expenditure and how much in subnormal output. As regards output, the relevant data that can generally be assembled are:—

1. Approximate yields per acre of arable crops and hay, and quality of the products.
2. Output of livestock products per acre of pasture and fodder crops.
3. Livestock production figures—*e.g.* milk sales per cow; egg production per bird; weight of piglets at weaning; and age and weight of cattle, sheep, and pigs at slaughter.

Crop yields must, of course, be assessed not in relation to national averages but in relation to local standards; and, even so, allowance must be made for the inherent fertility of the particular farm or field. In certain areas, however, there are rather clearly defined soil types, and in some cases approximate figures for normal yields are available. For example, the

following are the approximate average five-year yields for each of the eight extensive soil types in East Anglia :—

	Wheat	Barley	Oats	Sugar Beet	Potatoes
	Cwt.	Cwt.	Cwt.	Tons	Tons
Norfolk loams	22·2	18·7	21·7	10·4	6·5
Suffolk ,,	24·3	19·5	22·1	11·6	8·4
Essex boulder clays	22·7	19·9	19·4	10·6	7·6
,, London ,,	23·9	20·0	20·5	10·6	7·7
London chalks	21·9	19·0	19·1	8·9	6·1
Cambs.-Hunts clays	20·1	17·5	16·1	9·3	6·5
Black fen	27·7	21·8	24·1	12·4	8·9
Silt (alluvium)	33·4	26·4	26·3	13·8	10·0

If, in a particular case, yields are poor in relation to the inherent possibilities of the local climate and the particular soil type, an effort should be made to identify the reasons. The commonest are probably (1) the use of ill-adapted varieties, (2) inadequate usage of fertilizers (especially nitrogen), (3) ineffective weed control, (4) late-sowing or planting, (5) imperfect control of diseases and pests, (6) inefficient tillage, (7) avoidable wastage in harvesting or storage. The quality of crop produce is of varying importance as between one crop and another, and there is, in some cases, a degree of incompatibility between high quality and high yield.

Net Output of Livestock Products per Forage Acre.—The efficiency of livestock production may be assessed by relating the net output of livestock products to the acreage of grass and forage crops, including land used for hay, silage, etc., and such other crops (oats, beans, etc.) as are used for stock feeding. Where a substantial proportion of the food requirements of pigs and poultry is produced on the farm, and where either of those enterprises is on a considerable scale, the calculation should embrace the whole of the livestock. Where such circumstances do not obtain it may be well to confine consideration to the grass-eating animals, and examine the pig and poultry enterprises separately (see p. 934). In the latter case the net output is derived from sales of milk, wool, and livestock (with allowance for change in valuation), with deductions for purchased feeding stuffs and of grass seeds and forage-crop seeds. The following

illustration applies to a small farm devoted mainly to milk production but carrying a small flock of sheep :—

Sales :		
Milk	£2850	
Wool	120	
Sheep	650	
Cows, heifers, and calves	600	
Increase in livestock valuation	120	
		£4340
Purchases :		
Sheep	£280	
Cattle	180	
Feeding stuffs	650	
Seed (grass, beans, etc.)	90	
		1200
Net livestock output		£3140
Fodder acreage :		
Grassland (pasture, hay, and silage)		87
Kale, roots, etc.		8
Oats and beans		14
		109

Livestock output per forage acre $\frac{£3140}{109} = £28.\ 16s.$

Net Output per Work Unit.—The efficiency of labour use over the farm as a whole is obtained by dividing the total net output by some measure of the labour employed. Some economists use " work units "—*i.e.* either the man-hour or the man-day, the latter being taken at eight hours. Others use the total wages paid ; the answer is thus expressed in terms of net output per man-hour, per man-day, or per £100 of wages.

The measure of efficiency may be derived from either of two sets of data—viz. the average work units per acre of crops and grass and per head of livestock (see p. 846) or the average man-day units for the appropriate size and type of farm (see p. 847).

In the former case the theoretical labour need is calculated from the average work units per acre of crops and per head of livestock as set out in the table (with an addition of 15 per cent. for overheads), and the amount of labour used on the particular farm is compared with the calculated need. In the latter case the labour used per acre is compared with the average figure for costed farms of the appropriate group. For example, if a particular light-land arable farm of 130 acres uses 9·5 man-day

units per acre, as compared with the average of 7·3 for the appropriate group, it would appear that the labour use is rather seriously inefficient.

The degree of efficiency of pig and poultry enterprises can best be measured by physical rather than financial data, one reason being that output is little affected by climatic or soil conditions, and another that physical inputs and outputs can be easily recorded. Average figures are as follows :—

Poultry.

Food Requirements :

Laying birds—		
Range or deep litter	20 cwt. per year	
Battery	25 ,, ,, ,,	
Rearing	7 ,, per head	

Egg Production :	Year	Winter
Battery	200	100
Hen yard	180	80
Free range	150	60

Man-hours per Bird per Year :

Battery	2·8
Hen yard	1·9
Free range	2·6

Breeding Pigs.

Litters per sow per year	1·65
Pigs born alive per litter	9·2
,, ,, ,, year	15·2
Pigs weaned per litter	7·5
,, ,, sow per year	12·4

Bacon Pigs.—Weaning till slaughter (at 200 lb. liveweight). 4·25 lb. meal per pound liveweight gain (6½ cwt. per pig).

FARM BUDGETING

A farm budget consists of estimates of capital and labour requirements and of expenditure and income for a particular holding to be operated on some new plan. In some cases a radical change of the existing system may be contemplated—for example, a change from an all-grass system, with cattle fattening and sheep breeding, to one of ley farming with cereals, potatoes, and milk production as the main enterprises. In such cases a *complete budget* for the new system is required, and its estimated profitability is compared with the known profitability of the existing system. At the same time estimates are made of labour

and capital requirements. The examples set out on pages 900-913 indicate the form that a complete budget should take.

More commonly the change contemplated is less revolutionary, in which case the better approach is by what is called *partial budgeting*, *i.e.* the estimation of the effects of the proposed changes on capital and labour requirements and on profitability.

A budget must, of course, be based on some set of assumptions about the economic conditions that will obtain in the future; for instance, we may assume that there will be no material change in costs or prices, or that this relationship will become more or less favourable. Again, the assumption may be that the existing relationships between the prices of different farm products will continue to obtain or, alternatively, that the existing relationship will change—*e.g.* that beef prices will tend to rise and milk prices tend to fall. It is often desirable to consider two or more alternative farming plans and to estimate their relative profitability under two or more sets of assumptions in regard to future trends of costs and prices.

The Farm Economics Branch of Cambridge University has published a study [1] which well illustrates the procedure. The subject of study was a holding of 158 acres, fairly typical of a considerable group, situated on a reasonably fertile boulder-clay soil in the Eastern Counties. Table I sets out the existing organization. The cows provided milk for the farmer's household and the farm staff, while the store cattle were used mainly to convert straw into dung.

TABLE I

Crops:	Acres	*Livestock:*	Nos.
Wheat	37	Horses	3
Barley	37	Milk cows	2
Oats	4	Calves	2
Sugar-beet	12	Store cattle	12
Fodder beet	2	Boar	1
Mustard seed	12	Sows	6
Red clover	10	Laying hens	200
Mixed seeds	8		
Fallow	4	Sold annually—	
Permanent pasture	28	Capons	200
Waste and buildings	4	Weaner pigs	78
Total acres	158		

The average trading account is set out in Table II.

[1] "Planning a Farm for Higher Productivity," *Report No.* 41, 1954.

TABLE II

Purchases and Expenses:		*Sales and Receipts:*		
Rent	£307	Wheat	£1100	
Labour	998	Barley	840	
Seed and fertilizers	592	Sugar-beet	864	
Feeding stuffs	785	Seed crops	458	
Livestock	582			£3262
Fuel and machinery	593	Cattle	£678	
Other expenses	580	Pigs	429	
		Poultry and eggs	845	
	£4437			1952
Farm Income	777			
	£5214			£5214

The regular farm staff consisted of three men and one girl. The womenfolk of the farm were employed to single most of the beet crop, and an additional male worker was employed for a period of about ten weeks for the grain and root harvest. A contractor had been regularly employed to combine-harvest a substantial part of the corn crop.

Five provisional plans were examined, by partial budgeting, from the point of view of increasing the level of profitability.

Plan I has the object of reducing the regular labour force by one man. This implies mechanization, especially aimed at reducing labour needs at the three peak periods—viz. the late spring, cereal harvest, and beet harvest. The plan necessitates the purchase of a mid-mounted tractor hoe, a combine harvester, and a mechanical topper and digger for the sugar-beet crop. The partial budget under this plan is shown in Table III.

TABLE III

Additional Expenditure:		*Reduced Expenditure:*	
Depreciation and upkeep of new machines	£172	Wages of one man	£294
Casual labour or overtime	51	Contract combining (no longer required)	196
	£223	Threshing (no longer required)	52
Additional profit	319		
	£542		£542

This plan would leave the output virtually unchanged, would require the investment of something between £1500 and £2000 of additional capital, but is estimated to produce fully £300 of additional profit.

Plan II envisages the retention of the existing labour force and equipment, together with an increase in net output. Crop yields are already fairly high but the permanent pasture is understocked. With moderate usage of fertilizers, 16 acres would suffice to carry the existing head of stock, permitting 12 acres to be added to the tillage area. The crop chosen must be one which will not compete for labour at peak periods, and peas (for threshing) would appear to meet this requirement. The partial budget for this plan is shown in Table IV.

TABLE IV

Increase in Expenses:		*Increase in Receipts:*	
Overtime labour	£11	Peas sold	£360
Extra tractor and machinery expenses	32		
Fertilizers	70		
Seed	108		
Upkeep of fence	6		
Combine harvesting (by contract)	48		
	£275		
Additional profit	85		
	£360		£360

Plans III, IV, and V assume that the existing labour force is retained while the scheme of mechanization adopted in Plan I is carried through, the labour so released being used to increase output.

Under **Plan III** the store cattle and the pigs would be replaced by a dairy herd, composed of fifteen cows with "followers." This change, though it would add substantially to the farm income, would involve some reorganization of the cropping, the replacement or re-training of labour, and an adaptation or an addition to the farm buildings. Moreover, as appears from the table on page 939, the estimated profitability is lower than that of Plan IV.

Plan IV is based on the intensification of the pig and poultry enterprises—the carrying on of the pigs to bacon weight (instead of selling these as weaners) and the doubling of the laying flock. The existing buildings will accommodate the extra stock, provided that the store cattle in winter are reduced from twelve to six. The total amount of farmyard manure produced will then be substantially maintained. The only cropping change indicated

is the replacement of a few acres of "seeds" by barley or other cereal for feeding to the pigs and poultry. The labour saved by mechanization under Plan I would be sufficient to meet the needs of the pig and poultry enterprises. Table V shows that (as compared with Plan I) the additional profit is estimated at £638, implying a total profit of £1734.

TABLE V

Increase in Expenses:		*Increase in Receipts:*	
Wages	£243	Pigs	£1320
Feeding stuffs for pigs and poultry	963	Poultry and eggs	629
Pig replacements	95	Wheat	70
Depreciation of poultry batteries	50	Barley	96
Miscellaneous costs	69	*Reduction in Expenses:*	
Reduction in Receipts:		Seed and fertilizer	15
Cattle (net)	72		
	£1492		
Additional profit	638		
	£2130		£2130

Plan V.—It will be obvious that the change envisaged under Plan II—the reduction in the acreage of pasture to make room for peas—will be equally appropriate as a modification of Plan IV. Indeed, unless the number of summer cattle is maintained, the redundant acreage of pasture will be larger than 12 acres. Plan V, however, assumes 12 acres of peas. The calculated effect of introducing the pea crop will, however, be different from that set out in Table IV, for the reason that there will be no need to have the crop harvested by contract. The appropriate calculation is made in Table VI.

TABLE VI

Increase in Expenses:		*Increase in Receipts:*	
Additional use of—		Peas sold	£360
Tractor and implements	£33		
Combine	18		
Seed	108		
Fertilizer	70		
Upkeep of fence	6		
	£235		
Additional profit	125		
	£360		£360

Table VII gives estimates of revenue and expenditure, farm income and net output under the existing system and also under each of the five plans, together with a measure of the output per man in each case. It will be noted that the prospective income from Plan V is considerably more than double that obtained under the existing system.

TABLE VII

		Plan I	Plan II	Plan III	Plan IV	Plan V
	Present Organ-ization	Mechan-ization	Pea Crop	Mechan-ization plus Dairy Herd	Mechan-ization plus Pigs and Poultry	Mechan-ization plus Pigs and Poultry plus Pea Crop
Revenue—	£	£	£	£	£	£
Wheat	1100	1100	1100	1100	1170	1170
Barley	840	840	840	1058	936	936
Sugar Beet	864	864	864	864	864	864
Seed crops	458	458	458	...	458	458
Peas	...	...	360	...	...	360
Crop sales	3262	3262	3622	3022	3428	3788
Milk	...	...	...	1425	...	...
Cattle	678	678	678	214	354	354
Pigs	429	429	429	...	1749	1749
Poultry and eggs	845	845	845	845	1474	1474
Livestock sales	1952	1952	1952	2484	3577	3577
Total sales	5214	5214	5574	5506	7005	7365
Expenditure—						
Wages	998	755	1009	1031	998	998
Seed	116	116	224	226	104	212
Fertilizers	476	476	546	526	473	543
Feeding stuffs	785	785	785	616	1748	1748
Livestock	582	582	582	93	425	425
Contract	328	80	376	80	80	80
Fuel and machinery	593	765	625	786	765	816
Other costs	252	252	258	466	371	377
Rent	307	307	307	307	307	307
Total expenses	4437	4118	4712	4131	5271	5506
Farm income	777	1096	862	1375	1734	1859
Net output	3731	3731	3983	4571	4728	4980
Increase in output per man (per cent.)	...	26	6	21	28	35

It remains to consider the effect of any major price changes upon the relative profitability of the existing system and each of the five plans. The calculated effects of a number of downward changes in prices are set out in Table VIII.

TABLE VIII

	Present Organ-ization	Plan I	Plan II	Plan III	Plan IV	Plan V
	£	£	£	£	£	£
Present prices . . .	777	1096	862	1375	1734	1859
1. Pig prices fall 15 per cent.	713	1032	798	1375	1472	1597
2. Pig prices fall 10 per cent.; poultry and eggs 20 per cent.	566	885	651	1206	1265	1390
3. Milk prices fall 10 per cent.	777	1096	862	1232	1734	1859
4. Crop sales fall 30 per cent.	−201	118	−224	469	705	722

It will be observed that, under each of the assumptions, Plan V retains its place as the most profitable.

CHAPTER V

MARKETING

FARM products may be marketed by a wide variety of means. It is impossible to enter here into all the details, but it seems necessary to state the general principles and to give examples of the commoner marketing channels.

The first principle of marketing is to provide the prospective buyer with all the information that he needs in order to be able to form a true estimate of the value of the particular article.

1. The first means to this end is to present the actual article that is for sale and at the same time to answer in advance any questions that an intending buyer might be likely to ask. This is the procedure most commonly used in the case of breeding animals and store stock. Thus a lot of ewes may be penned in a market or offered through an auction. The seller will state whether or not the ewes are guaranteed correct in udder and whether they are whole or broken-mouthed; whether they are all of the same age or whether of mixed ages, etc. In the case of a dairy cow the age, if known, may be stated, and the animal may be guaranteed correct of bag. The date of last calving or the probable date of the next calving should also be stated. If the cow has been milk-recorded her yield may be given, and if she has a pedigree this should be set out, with any relevant information about her ancestors. Information so given carries a guarantee of accuracy and a buyer may, if he finds that he has been given incorrect information, repudiate the purchase.

2. The bulk of the commodity may not be exposed, the buyer being shown a *sample*. This is the normal method of selling corn in this country. The farmer either takes to market, or sends to an agent, a small quantity of his grain and a sale is negotiated. The buyer has naturally the right to repudiate the contract if he can show that the bulk does not conform to sample.

3. The sale may be on *specification—i.e.* a guaranteed description of the article. Thus a seller of artificial manure is required by law to state the percentage-content of nitrogen, potash, water-soluble phosphoric acid, and insoluble phosphoric

acid which the manure contains; a seller of certain classes of feeding stuffs (oil cakes and meals, compound feeding stuffs), the percentage-content of albuminoids (protein), oil, and fibre. Seeds are sold on a guarantee of purity and germination. Potatoes are sold in size grades, and with a general guarantee of quality—*e.g.* the variety is stated, the bulk is guaranteed to be substantially sound and free from blight and to have been dressed over a specified riddle.

In certain cases, it is important to note, a form of words used to describe an article is held, in law, to give an implied guarantee. Thus if a farmer sells "seed oats" he is giving an implied guarantee of a minimum germination, or if he sells "Majestic" seed potatoes, an implied guarantee of a certain percentage purity of this variety. Similarly, "barley meal" means a meal, made from barley with not more than a definite percentage of impurities, which has not been treated by sifting, etc.

4. Commodities may be sold by *grade*, which grade is determined by an authority who is entirely independent. Thus Canadian wheat is graded as "No. 2 Manitoba Hard," etc., and the various grades are bought and sold unseen. Similarly, bacon pigs, supplied to factories, may be graded according to carcass measurements and paid for at rates which vary with the grade. Fat cattle, during the war and up till 1954, were purchased by the Ministry of Food, and the individual animals were graded according to their estimated dressing percentage (dressed carcass weight as a percentage of live weight). Milk is graded in this country according to the standard of hygiene maintained in its production, and there are special premiums for the milk of tuberculin-tested cows and for milk derived from the Channel Islands breeds. In other countries the scale of payment is related to the average content of butter-fat. Eggs are now frequently graded, as "specials," "standard," etc., according to weight. Sugar-beet is paid for, by the factory which has contracted to receive it, on washed weight and sugar percentage.

We may next classify and shortly describe the actual means of effecting a sale.

1. The simplest method is by *private treaty*. A seller or his agent approaches a likely buyer, or *vice versa*, and the price and other conditions of sale are arranged. A slight modification of this is what is sometimes called *private auction*. In this case, for example, corn merchants assemble at a certain place and

time and a farmer presents a sample of seed oats to one after another until he obtains what he considers a satisfactory offer. In deciding which offer to accept he naturally considers not only the price bid but also the credit of the bidder.

2. In certain parts of the country the normal method of marketing store stock and dairy cattle is by public auction. The same method may be applied to pedigree animals, and to a variety of commodities including growing crops of potatoes, grass keeping, fodder roots, etc. Auction is the usual procedure at farm sales, when a tenancy has changed hands. The sale is conducted by a licensed auctioneer, who lays down certain conditions of sale. Ordinarily, he does not bind himself to accept the highest or any bid: he lays down conditions regarding payment; he generally permits the seller, if he so desires, to set a reserve price on each lot, or he may allow the seller to make one or more bids for his own property; and he lays down a certain procedure to be followed in the case of disputes. Finally, he insists that the goods sold shall conform to any warranty or specification which the seller gives, either verbally or in writing. In large markets this method of selling is generally satisfactory. Small auction sales are frequently spoilt by the formation of buyers' "rings"; *i.e.* a group of buyers delegate one of themselves to bid on behalf of the group, and the stock so purchased is later divided up.

3. A modification of the ordinary auction system, which is widely used in other countries but is rarely found in Britain, is the *Dutch auction*. Here the lot is put up at a price which is considered to be above its value, the price is reduced by stages until a bid is made, when the lot is at once sold. The first bidder (instead of the last) thus becomes the purchaser. In Holland the system is mechanized by having a pointer, which is moved by the auctioneer, travelling round a dial on which the price series is marked. Each customer has an electric button by which he can stop the pointer at the price which he is prepared to offer. The pressing of the button also lights up the buyer's registered number and the sale is immediately registered by a clerk.

4. Sales may also be effected through *commission agents*. A commission agent is prepared to undertake the sale or purchase of a particular commodity and makes a charge, generally on a percentage basis, for his services. A seller on commission may sell in bulk, or on sample, or by grade or description. An example

of this system is seen at Covent Garden market in London. The grower consigns his fruit or vegetables to his commission agent, generally after a telephone inquiry about the expected supplies and demand. The commission agent gets in touch with likely wholesale buyers, sells the goods for the best price obtainable, collects the proceeds, deducts his commission and marketing charges, and remits the balance to the seller. In many cases the commission agent supplies the necessary containers for the goods, making a special charge for their use. Dead-meat was sold in Smithfield and other markets by the same procedure up till 1939.

5. A sale may be effected by an agreement between the buyer and seller to accept the decision of a third party on the price at which the goods shall change hands. Thus in the case of a change of tenancy the outgoing and incoming tenant may agree that live and dead stock, growing crops, tillages, etc., shall be valued by a single individual. A modification of this procedure is that each party appoints a valuer to act on his behalf, and the two valuers appoint an arbiter or " oversman " to give a decision in case of disagreement. Sale at the valuation of a third party may be applied to any kind of article.

6. Still another method of sale is to put an article up for *private tender*. The offer of sale is advertised in the press or by circular, or both, to possible buyers. Time is allowed for the inspection of the goods and written tenders are received up till a specified date. The letters of tender are then opened and the highest offer is ordinarily accepted.

7. Goods may also be produced by the farmer *on contract* at prearranged prices. In the case of sugar-beet the farmer contracts to grow, for a certain factory, a given acreage of beet, and to deliver the total produce to the factory at times and under conditions which are arranged. It is also a common practice in certain areas to grow potatoes for merchants on contract. The land is taken at a certain sum per acre, the farmer applying farmyard manure, doing all tillage, sometimes supplying planters and, less commonly, pickers as well. The merchant on his part supplies seed, artificials, and the balance of the labour.

Many farmers are also accustomed to " buy forward " their requirements in the way of feeding stuffs and fertilizers. Thus a farmer may contract, say, in July, for his winter supplies of cake and meal, to be delivered at the prices fixed when the contract is made, over the period when he expects to require them.

It should be noted that in certain cases sales can be made only through specially authorised persons or bodies. Thus all sales of hops must be arranged by the Hops Marketing Board. All sales of potatoes, in quantities exceeding a specified maximum, must be made to merchants authorized by the Potato Marketing Board, and sales on commission are prohibited. All sales of milk by producers, except producer-retailers, are made through the Milk Marketing Boards, which collect the proceeds and, after making necessary deductions, remit the balance to the producer.

While in this country most auctioneers, dealers, merchants, and commission agents are ordinary individuals or companies trading for profit, any of their functions may be carried out by voluntary Farmers' Co-operatives. The members of these Co-operatives subscribe the necessary share capital, the interest on which is a first charge on profits. Surplus profits are distributed as a trading dividend, *i.e.* the sum received by a member is determined by the amount of his trading with the Society. Co-operative Societies may collect, pack, grade, and transport farm produce or farm requirements as well as buy and sell on behalf of their members.

Every sale should be made with a distinct understanding regarding the time and method of payment. In certain cases the terms are cash on delivery; in many cases, however, the seller allows to the buyer a certain amount of credit. Thus certain auction companies supply live stock to farmers on an instalment system. In other cases there is three, six, or even twelve months' credit at the price agreed, with the option of a discount for cash. Sometimes rather indefinite credit is allowed, subject, of course, to a prearranged rate of interest on the sums remaining outstanding.

In the sale of agricultural produce there is frequently a good deal to be gained by careful grading of the produce. If a farmer has 300 store lambs to sell he will generally obtain a higher average price if he sells in well-assorted lots of, say, 50 rather than in lots run off at random. The advantage to the purchaser is obvious, for he will be able to have all the lambs fat within a relatively short space of time, and will have, in turn, a comparatively level lot to sell. With commodities such as fruit and vegetables careful grading is very important; standard packages should be used and each package should contain the same quality throughout.

In certain cases the difficulty arises that the farmer has only a small quantity of produce and that of mixed quality. The clip of wool from a small flock is a case in point. Most wool-buyers require large lots of uniform quality, and hence a small mixed lot attracts very little attention. One satisfactory method of dealing with this problem is to form a Co-operative Wool-growers' Society, which employs an expert to class the fleeces and to make up large batches for sale. Some wool-brokers are prepared to deal with mixed lots in the same way. The individual member is usually paid part of the value of his clip as soon as it is delivered; he is credited with the weight of each of the various classes of wool that he has supplied, and is paid the balance due to him when the wool is sold.

With certain commodities, especially such as are liable to damage in transit, packing as distinct from grading is an important point.

The Ministry of Agriculture in the period between the wars established National Marks for most classes of fruit and vegetables, as well as eggs and many other commodities. Inspectors are employed to ensure that goods sold under a particular National Mark Grade actually conform to the prescribed standard.

One further point in connection with marketing is the cost and method of transport. There is generally the choice between rail and road transport, and sometimes the one and sometimes the other will be the cheaper. As regards railway rates, there is often a relatively low rate per ton for large consignments—*e.g.* a full wagon-load of cattle or sheep or a six-ton lot of fertilizer or feeding stuffs. Speed of delivery and risk of damage or deterioration must, of course, be considered as well as cost.

Under the Agriculture Act, 1947, price guarantees are provided for wheat, rye, barley, oats, potatoes, and sugar-beet; for fat cattle, sheep and lambs, pigs sold for slaughter (whether for pork or bacon); for milk and eggs.

With the return to private trading in these commodities in 1954 new methods were devised for implementing the price guarantees. The general aim is to make good any deficiency between the market price and the guaranteed price, but the method employed varies as between one particular commodity and another.

Wheat.—The "standard price," fixed at the annual price review, is subject to seasonal variation, rising from the time of

harvest until the end of the cereal marketing year. If the average realized price, over a particular price period, falls short of the standard price, the difference is made good by the State. All sales must be registered in order to qualify for deficiency payments.

For **Rye** the system is the same, except that the standard price is not subject to seasonal variation.

Barley and Oats.—Whereas wheat and rye are ordinarily grown for sale, large quantities of barley and oats are consumed on the farms where they are grown. It would thus be impracticable to base deficiency payments on quantities sold and prices realized. The deficiency payment is therefore based on the acreage grown and on the national average yield. This system results in relatively high returns, per hundredweight, in cases where the yield is low, and in relatively low returns, per hundredweight, in cases where the yield is high.

For **Potatoes** the guarantee is implemented through a support-price system, operated through the agency of the Potato Marketing Board. The market price of potatoes, unlike that of grain, is little influenced by imports, and the purpose of the guarantee is to protect producers against low returns in years of high yield. The support price is fixed at a somewhat lower level than that which would be appropriate to a fixed price. Since transport and marketing costs vary from area to area, separate support prices obtain in the five regions into which the country (Great Britain and Northern Ireland) is divided.

Sugar-beet is grown under contract with the British Sugar Corporation. The basic price applies to beet of 16·5 per cent. sugar content, and the actual price of each consignment is determined on the basis of its sugar content, with a deduction for tare (dirt tare and top tare). The corporation bears transport costs in excess of those for a haul of about forty miles.

Fat Cattle, Sheep, and Lambs have a double guarantee—individual and collective. The two-fold guarantee applies to steers, heifers, " special " young cows, and first-grade " clean "[1] fat sheep and lambs. Better-quality cows, other than " special young cows," qualify for the collective but not for the individual guarantee.

The individual guarantee ensures that a particular animal, sold at auction, will realize to the seller not less than a price which,

[1] The term " clean " excludes rams and ewes.

depending on its grade, is known in advance. The collective guarantee ensures that animals of a particular grade, over a particular period, will realize not less than a certain average price which again will be known in advance. Cattle prices are per live hundredweight (gross weight) and those of sheep and lambs are per pound estimated dressed carcass weight. The collective guarantee applies to sales by grade and deadweight as well as at auction on the hoof; and also to private sales, with the proviso that the stock must be presented at a market centre to be weighed and graded.

Pigs.—Clean pigs sold on the hoof, whether at auction or otherwise, are eligible for the collective guarantee. Pigs sold at auction are also eligible for the individual guarantee. The guaranteed prices are, however, related, on a sliding scale, to the price of a standard feed mixture, and this may vary from month to month.

Both pork and bacon pigs may be sold by deadweight and grade, the farmer's receipts being supplemented to the level of the standard price.

Milk.—Milk is marketed through Marketing Boards—one for England and Wales, one for each of the three Scottish areas, and one for Northern Ireland. Each area has a **Standard Quantity** allocated to it, equal to its estimated sales off farms in 1953-54. Separate price guarantees are in force—a higher figure for the **primary proportion** and a lower for the remainder. The primary proportions for 1954-55 were about 80 per cent. of the total sales off farms in the preceding year. The guaranteed price for each area is related to the Standard Quantity for that area; hence, if total sales off farms exceed the Standard Quantity, the effective level of the guaranteed price per gallon of total production will fall.

Eggs.—The guaranteed prices, as decided at Annual Reviews, are average support prices for first-quality eggs, with a deduction for dirty eggs. There is no guarantee for second-quality eggs. The average annual support price is related to the ruling price of a standard feed mixture over a period of thirty-two weeks preceding the period in which the eggs are sold.

APPENDIX

TABLE I

NUTRIENTS REMOVED FROM SOIL BY CROPS

(In lb. per acre per annum)

	Weight	Nitrogen	Phosphoric Acid (P_2O_5)	Potash
Wheat . .	18 cwt.	35·2	15·2	9·9
Barley . .	18 ,,	31·5	14·4	8·7
Oats . . .	18 ,,	38·5	13·8	9·7
Beans . .	18 ,,	82·0	25·3	25·9
Hay . . .	1½ tons	49·0	12·3	50·9
Clover . .	2 ,,	102·0	24·9	83·4
Cabbages . .	25 ,,	168·0	57·9	55·0
Turnips . .	17 ,,	63·0	22·4	108·6
Swedes . .	14 ,,	70·0	16·9	63·3
Mangolds . .	22 ,,	87·0	33·9	222·8
Potatoes . .	6 ,,	47·0	21·5	76·5

Note.—In the above table, the straw, tops, shaws, etc., are left out of account.

TABLE II

MANURE SOWING TABLE

Showing the quantity of manure requisite to be sown in a certain number of yards, equal to 1 cwt. to the acre, in imperial measure, in drills from 36 to 22 in. apart.

Distance of Drill in inches apart	Number of the Lineal Yards in the Imperial Acre	Length of Yards for lb. equal to 1 cwt. Manure per Acre
36	4840	43
35	4978	44
34	5124	45
33	5280	47
32	5445	48
31	5620	50
30	5808	51
29	6008	53
28	6222	55
27	6453	57
26	6701	59
25	6969	62
24	7260	64
23	7575	67
22	7920	70

Example.—Suppose the drills to be 36 in. apart—1 lb. of guano to 43 yds. is equal to 1 cwt. per acre; 2 lb. to 43 yds. is equal to 2 cwt. per acre; and so on, every lb. for 43 yds. being equal to 1 cwt. per acre.

From the *North British Agriculturist Year Book.*

TABLE III.—COMPOSITION AND NUTRITIVE VALUE OF FEEDING STUFFS

	Average Composition per cent. as shown by Analysis						Digestible Nutrients per cent.					Calculated from Digestible Nutrients		
				Carbohydrates						Carbohydrates			Per 100 lb.	
	Dry Matter	Crude Protein	Oil	Soluble	Fibre	Ash	Crude Protein	True Protein	Oil	Soluble	Fibre	App. Ratio S.E./P.E.	Protein Eqvt. (P.E.)	Starch Eqvt. (S.E.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Pasture Grass														
Very leafy	18	4·0	0·6	7·5	3·6	2·3	3·3	2·3	0·3	6·1	3·0	4	2·8	10·8
Leafy	19	3·3	0·5	8·5	4·5	2·2	2·5	1·8	0·3	6·7	3·6	5	2·2	11·3
Little stem: early flowering stage	21	3·0	0·7	9·8	5·4	2·1	2·1	1·6	0·4	7·5	4·2	6	1·9	12·2
Stemmy: flowering stage .	23	2·4	0·5	11·7	6·2	2·2	1·6	1·3	0·3	8·4	4·6	9	1·5	12·7
Seed set: full flower . .	25	2·1	0·6	13·1	7·4	1·8	1·3	1·0	0·3	9·3	4·8	10	1·2	12·8
Green Legumes														
Clover: very young . .	17	4·3	0·6	7·2	3·1	1·8	3·4	2·9	0·4	6·0	2·1	3	3·2	10·0
Bud stage	17	3·5	0·6	7·3	4·1	1·5	2·6	2·2	0·4	5·9	2·5	4	2·4	9·4
Early flowering stage . .	19	3·4	0·7	8·0	5·3	1·6	2·5	2·1	0·5	6·3	2·9	5	2·3	10·3
Full flower	21	3·4	0·7	9·4	5·9	1·6	2·2	1·9	0·4	6·7	2·6	5	2·1	10·7
Lucerne: very young . .	15	3·8	0·4	5·7	3·3	1·8	3·2	2·1	0·1	4·6	2·1	3	2·6	9·0
Bud stage	22	4·5	0·5	9·0	6·2	1·8	3·6	2·4	0·1	6·8	3·1	4	3·0	11·3
Early flowering stage . .	24	4·1	0·4	9·9	7·2	2·4	3·1	2·0	0·1	6·6	3·2	4	2·6	10·3
Beans: early flowering stage .	15	3·2	0·8	5·7	3·3	2·0	2·3	1·5	0·5	4·1	1·6	4	1·9	7·1
Peas: early flowering stage .	17	3·5	0·6	5·5	5·8	1·2	2·4	1·6	0·3	3·8	3·2	4	2·0	7·1
Vetches: early flowering stage .	17	3·1	0·5	6·9	5·0	1·5	2·1	1·4	0·3	4·8	2·2	4	1·8	7·3
Green Forage Crops														
Barley: in flower . . .	30	2·1	0·5	16·0	9·5	1·9	1·4	1·2	0·3	11·6	6·1	12	1·3	15·4
Cabbage: drumhead . .	11	1·5	0·4	5·9	2·0	1·2	1·1	0·7	0·2	4·6	1·4	7	0·9	6·6
Open-leaved	15	2·5	0·7	7·9	2·3	1·6	1·8	1·2	0·4	6·4	1·7	6	1·5	9·3
Kale: marrow-stem . .	14	2·1	0·3	7·3	2·5	1·8	1·6	1·0	0·2	6·5	1·5	7	1·3	9·1
Thousand-headed . . .	16	2·2	0·4	8·5	3·2	1·7	1·7	1·2	0·2	7·6	1·8	7	1·4	10·4
Maize	19	1·6	0·5	10·2	5·5	1·2	1·0	0·6	0·3	6·6	3·0	11	0·8	8·9

Mangold leaves	11	2·4	0·4	4·6	1·6	2·0	1·6	1·0	0·2	3·5	0·9	4	1·3	5·3
Mustard	15	2·9	0·4	7·4	2·9	1·4	1·9	1·3	0·2	4·9	1·5	5	1·6	7·2
Oats: in flower	23	1·9	0·6	10·3	8·4	1·8	1·4	1·2	0·4	6·4	4·9	8	1·3	9·9
Oats and vetches	21	2·3	0·5	9·2	7·3	1·7	1·6	1·3	0·4	5·9	4·0	6	1·5	9·0
Rape	14	2·8	0·8	5·6	3·5	1·3	2·0	1·3	0·5	3·9	1·9	4	1·6	6·9
Rye: pre-flowering	23	2·9	0·9	10·1	7·4	1·7	2·1	1·4	0·5	6·9	4·8	7	1·7	11·1
Sugar-beet tops	16	2·0	0·5	8·6	1·6	3·3	1·4	0·9	0·3	7·1	1·1	8	1·1	8·5
Swede and turnip tops	12	2·3	0·5	5·5	1·5	2·2	1·6	0·4	0·2	4·3	0·8	6	0·9	5·5
Hay *														
Clover (see Seeds: high clover)														
Barley	85	6·9	1·9	45·3	24·6	6·3	4·5	3·6	0·7	28·6	15·3	10	4·0	41·2
Lucerne: before flowering	85	16·4	2·4	31·5	27·3	7·4	12·2	8·2	1·1	21·4	11·4	3	10·2	32·2
Full flower	85	14·5	2·7	29·7	30·0	8·1	9·9	6·3	1·2	18·4	13·4	3	8·1	27·1
Meadow: no stem, all leaf, short	85	13·7	3·0	41·0	19·5	7·8	9·3	6·6	1·5	30·5	12·8	6	8·0	49·3
Early flowering stage	85	10·0	1·6	40·0	26·6	6·8	5·4	4·5	0·8	25·3	18·2	8	5·0	40·5
Flowering stage	85	7·6	1·5	40·8	28·7	6·4	3·4	2·8	0·7	24·5	17·9	11	3·1	35·6
Full flower, seed set	85	4·8	1·2	43·1	30·6	5·3	2·4	1·6	0·6	25·4	16·8	16	2·0	32·5
Oat	85	8·0	2·6	40·3	27·4	6·7	4·3	3·4	1·5	22·6	14·3	8	3·9	32·5
Oats and vetches	85	11·7	3·4	36·7	24·5	8·7	6·6	4·2	1·7	23·6	12·4	7	5·4	34·7
Sainfoin: before flowering	85	15·6	3·2	34·3	25·1	6·8	11·0	7·9	2·1	25·4	10·8	4	9·5	39·6
Full flower	85	13·4	2·6	33·1	28·5	7·4	9·8	7·6	1·6	25·8	12·0	4	8·7	37·8
Seeds: high clover	85	12·2	1·3	42·2	22·1	7·2	7·9	6·1	0·7	31·1	12·2	6	7·0	45·0
Medium clover	85	9·1	1·2	43·2	25·2	6·3	5·0	3·9	0·6	30·4	15·1	10	4·5	42·8
Low clover	85	7·4	1·2	45·0	25·6	5·8	3·9	3·1	0·6	32·0	15·7	13	3·5	44·3
Wheat	85	5·6	1·6	46·7	24·9	6·2	3·1	2·6	0·9	28·9	14·5	14	2·9	39·8
Artificially Dried Crops														
Grass: very leafy	90	18·7	3·0	40·6	17·7	10·0	14·1	13·0	1·7	30·5	13·3	4	13·6	54·1
Leafy	90	15·0	2·6	40·7	20·9	10·8	10·0	8·6	1·5	31·0	15·9	6	9·3	51·7
Little stem: early flowering stage	90	12·1	2·2	42·3	24·4	9·0	7·3	6·4	1·1	31·4	18·8	7	6·8	51·2
Stemmy: flowering stage	90	10·4	2·2	42·7	24·4	10·3	5·8	5·1	1·2	30·9	18·6	9	5·5	49·5
Lucerne or clover: bud stage	91	22·3	2·9	36·4	18·0	11·4	15·9	11·2	1·3	28·4	9·5	4	13·6	50·1
Early flowering stage	91	16·2	2·4	37·7	24·5	10·2	11·6	9·3	...	27·8	11·2	4	10·5	44·1
American leaf meal	91	21·4	1·9	40·6	16·0	11·1	16·3	14·7	0·7	31·5	7·9	3	15·5	50·2
Clover meal	90	10·5	1·4	44·1	26·4	7·6	5·7	4·2	0·6	30·5	14·0	8	5·0	42·0

* The figures for hay apply to samples that have suffered no material weather damage.

TABLE III.—COMPOSITION AND NUTRITIVE VALUE OF FEEDING STUFFS—*continued*

	Average Composition per cent. as shown by Analysis						Digestible Nutrients per cent.					Calculated from Digestible Nutrients		
				Carbohydrates						Carbohydrates			Per 100 lb.	
	Dry Matter	Crude Protein	Oil	Soluble	Fibre	Ash	Crude Protein	True Protein	Oil	Soluble	Fibre	App. Ratio S.E./P.E.	Protein Eqvt. (P.E.)	Starch Eqvt. (S.E.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Silage														
Clover	20	4·1	1·1	6·5	6·0	2·3	2·7	1·6	0·6	4·7	3·2	3*	2·1	8·9
Grass: leafy, high protein	20	3·5	1·0	9·0	5·0	1·8	2·8	1·2	0·5	7·2	4·0	4*	2·0	12·4
Early flowering stage	25	3·2	0·9	11·6	7·0	2·3	2·1	0·6	0·6	9·0	5·6	7*	1·4	14·5
Full flower, stack stage	25	2·9	0·7	10·9	7·9	2·7	1·2	0·5	0·5	6·9	5·8	10*	0·9	11·4
Kale: marrow stem	16	2·0	0·5	7·2	3·8	2·5	1·5	1·0	0·4	6·1	2·8	7*	1·3	9·8
Lucerne	17	3·7	1·4	4·8	5·0	2·1	2·5	1·5	0·7	3·3	2·1	3*	2·0	7·0
Maize	20	2·2	1·2	10·7	4·7	1·2	1·4	0·6	1·0	7·5	3·2	9*	1·0	12·1
Pea haulm and pods	25	3·7	1·5	9·1	6·4	4·3	2·1	0·2	1·4	6·3	3·6	5*	1·2	11·5
Potato, steamed	25	2·4	0·3	19·2	0·8	2·3	1·5	0·7	0·1	17·2	0·4	12*	1·1	18·6
Potato haulms	25	3·2	2·7	9·1	4·4	5·6	1·2	0·3	1·2	5·0	1·7	7*	0·7	8·3
Sugar-beet top	25	2·6	0·8	9·9	3·7	8·0	1·6	0·2	0·3	7·8	2·7	7*	0·9	10·8
Vetch and oat	25	3·4	0·7	10·2	7·8	2·9	1·9	0·9	0·5	6·7	4·8	6*	1·4	10·8
Roots														
Carrots	13	1·2	0·2	9·3	1·4	0·9	0·8	0·4	0·1	8·9	0·7	15	0·6	8·8
Kohlrabi	13	2·1	0·1	8·4	1·4	1·0	0·7	0·3	...	7·6	0·6	17	0·5	8·5
Mangolds	12	1·0	0·1	9·4	0·7	0·8	0·7	0·1	...	8·5	0·3	15	0·4	6·2
Parsnips	15	1·3	0·3	11·3	1·2	0·9	1·0	0·6	0·1	10·9	0·7	13	0·8	10·6
Potatoes	24	2·1	0·1	19·9	0·9	1·0	1·1	0·6	...	17·9	...	23	0·8	18·7
Potato flakes, dried	90	8·2	0·3	75·6	2·1	3·8	3·8	1·9	...	70·8	1·0	27	2·8	75·2
Sugar-beet	23	1·1	0·1	20·0	1·1	0·7	0·8	0·3	...	18·9	0·4	24	0·6	14·7
Pulp: wet	15	1·6	0·1	9·6	3·1	0·6	1·0	1·0	...	8·7	2·8	12	1·0	11·7
,, dry	90	8·9	0·6	59·1	18·3	3·1	5·3	5·0	...	54·0	16·3	12	5·1	60·6
,, molassed	90	10·8	0·4	58·2	15·1	5·5	6·3	3·0	...	53·0	13·5	12	4·7	58·3
Swedes	11·5	1·3	0·2	8·1	1·2	0·7	1·1	0·3	...	7·5	0·8	10	0·7	7·3
Turnips: soft	8·5	1·0	0·2	5·7	0·9	0·7	0·6	0·2	...	5·2	0·3	11	0·4	4·4

Straws														
Barley	86	3·3	1·8	42·4	33·9	4·6	0·8	0·6	0·6	22·5	18·3	39	0·7	27·4
Bean	86	4·5	0·8	33·0	43·1	4·6	2·2	1·3	0·5	22·0	18·7	12	1·8	21·5
Oat	86	2·9	1·9	42·4	33·9	4·9	1·0	0·8	0·6	19·4	18·3	26	0·9	23·8
Pea	86	9·0	1·6	33·5	35·4	6·5	4·3	3·4	0·7	18·5	13·7	5	3·9	19·4
Wheat	86	2·1	1·3	40·7	36·6	5·3	0·1	...	0·4	15·0	18·3	156	0·1	15·6
Chaff														
Bean	86	10·8	2·0	32·9	33·9	6·4	5·3	4·0	1·0	21·4	14·6	5	4·6	22·0
Linseed	88	3·5	3·4	34·8	40·5	5·8	1·4	1·0	1·7	12·9	12·1	15	1·2	17·5
Oat	86	6·0	2·1	44·8	22·8	10·3	2·2	1·7	1·0	21·9	10·2	15	2·0	29·0
Pea	86	9·8	1·2	33·7	35·4	5·9	4·9	3·7	0·5	20·2	15·9	5	4·3	20·1
Wheat	86	4·8	1·8	38·0	31·1	10·3	1·4	0·4	0·5	17·1	15·0	28	0·9	24·9
Chaff Meals														
Barley	86	5·9	1·4	41·2	20·8	16·7	2·9	2·8	0·3	16·8	6·4	7	2·9	20·3
Wheat	86	5·0	1·0	42·0	29·9	8·1	2·3	2·1	0·3	17·8	12·0	11	2·2	23·8
***Digested** Straw (caustic soda process)*														
Cereal straws	20	0·5	0·3	8·1	10·1	1·0	0·1	0·1	0·2	4·8	7·2	96	0·1	9·6
***Cereals** and Cereal Products*														
Barley	85	10·0	1·5	66·4	4·5	2·6	7·6	7·0	1·2	60·8	2·5	10	7·3	71·3
Bran	90	14·9	3·6	57·9	8·6	5·0	12·6	11·5	3·1	49·7	1·7	5	12·1	66·3
Dust	87	11·8	2·2	65·2	4·6	3·2	8·8	8·3	2·0	59·8	1·1	8	8·6	71·9
Brewers' grains: wet	32	7·4	2·8	14·4	6·0	1·4	5·4	5·1	2·4	9·0	2·4	3	5·3	18·2
„ „ dried	90	18·4	6·4	46·1	15·2	3·9	13·0	12·1	5·6	27·7	7·3	4	12·6	48·5
Distillers' grains: wet	26	8·3	3·0	10·3	3·6	0·8	6·2	5·8	2·6	6·3	1·7	3	6·0	16·1
„ „ dried	92	27·7	11·6	40·8	10·1	1·8	19·6	18·7	10·2	25·3	4·8	3	19·1	57·2
Ale and porter grains: wet	27	6·5	2·1	11·5	5·7	1·2	4·8	4·5	1·8	7·1	2·2	3	4·7	14·8
„ „ „ „ dried	90	19·7	6·7	42·9	17·5	3·2	13·9	13·0	5·9	25·6	8·4	4	13·5	48·8
Malt	93	13·7	3·1	64·6	9·0	2·6	11·0	8·8	2·4	56·2	4·5	7	9·9	71·2
Malt culms	90	24·4	2·0	42·4	14·0	7·2	19·9	12·0	1·5	30·9	12·7	3	15·9	43·4

* The figures for silages in these columns are calculated from digestible crude protein.

TABLE III.—COMPOSITION AND NUTRITIVE VALUE OF FEEDING STUFFS—*continued*

	Average Composition per cent. as shown by Analysis						Digestible Nutrients per cent.					Calculated from Digestible Nutrients		
	Dry Matter	Crude Protein	Oil	Carbohydrates: Soluble	Carbohydrates: Fibre	Ash	Crude Protein	True Protein	Oil	Carbohydrates: Soluble	Carbohydrates: Fibre	App. Ratio S.E./P.E.	Per 100 lb. Protein Eqvt. (P.E.)	Per 100 lb. Starch Eqvt. (S.E.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Cereals and Cereal Products—contd.														
Maize	87	9·9	4·4	69·2	2·2	1·3	7·9	7·4	2·7	63·7	0·8	10	7·6	77·6
Bran	88	8·4	4·2	61·9	11·6	1·9	5·5	4·8	3·6	53·3	3·9	13	5·2	66·9
Flaked	89	9·8	4·3	72·5	1·5	0·9	9·4	9·0	2·0	70·4	0·5	9	9·2	84·0
Germ meal	89	12·9	12·5	55·9	4·1	3·6	10·4	10·2	11·5	46·9	2·5	8	10·3	84·1
Gluten feed	90	23·7	3·4	56·9	3·5	2·5	20·1	18·5	2·7	49·5	2·5	4	19·3	75·9
,, **meal**	91	35·5	4·7	47·6	2·1	1·1	30·6	30·3	4·4	42·6	...	3	30·4	81·6
Hominy chop	90	10·6	8·0	64·4	4·4	2·6	7·0	6·1	7·3	58·1	3·3	12	6·6	78·2
Malt culms	87	20·8	14·6	39·8	5·8	6·0	17·5	10·7	12·5	35·1	4·5	4	14·1	59·8
Millet	87	10·5	3·9	60·7	8·1	3·8	8·0	7·4	3·1	45·5	2·7	8	7·7	58·5
Oats	87	10·4	4·8	58·4	10·3	3·1	8·0	7·2	4·0	44·9	2·6	8	7·6	59·6
Oat bran	90	7·9	3·6	50·7	21·8	6·0	4·0	3·6	2·0	35·4	8·0	12	3·8	45·2
Husks	86	1·9	0·5	45·8	32·4	5·5	...	...	0·2	16·5	10·7	...	...	18·3
Meal	92	16·1	6·7	65·6	1·6	2·0	12·0	10·5	5·4	48·1	0·8	5	11·3	61·6
Rice: polished	87	6·7	0·4	77·6	1·5	0·8	5·8	5·5	0·2	75·4	0·7	14	5·7	81·7
Meal	91	12·9	13·7	49·4	6·4	8·6	7·5	6·6	11·6	38·9	1·6	10	7·1	72·2
Sludge, dried	86	26·2	2·1	55·2	1·1	1·4	21·5	16·3	1·0	50·3	0·7	3	19·9	61·7
Rye	87	11·6	1·7	69·8	1·9	2·0	9·6	8·7	1·1	64·2	1·0	8	9·1	72·0
Sorghums (Dari, etc.)	89	9·6	3·8	71·3	1·9	2·4	7·7	6·7	3·0	60·6	1·0	10	7·2	74·2
Wheat	87	12·2	1·9	69·3	1·9	1·7	10·3	9·0	1·2	63·8	0·9	7	9·7	72·0
Feed: fine middlings	87	17·1	4·2	61·0	2·3	2·4	12·7	11·6	3·7	51·3	...	6	12·2	69·3
,, **coarse middling**	86	15·9	4·5	55·9	6·0	3·7	11·6	10·1	3·9	45·9	1·4	5	10·8	56·5
Bran	87	15·1	3·8	52·8	9·5	5·8	10·9	8·9	2·6	37·4	2·2	4	9·9	42·6

Leguminous Seeds														
Beans	86	25·5	1·5	48·7	7·1	3·2	20·2	19·4	1·2	44·3	4·1	3	19·8	66·0
Butter	89	23·6	1·1	56·2	3·7	4·4	15·6	14·8	0·7	52·2	2·3	4	15·2	68·2
Husks	88	3·5	0·2	37·1	42·9	4·3	...	...	0·2	21·3	37·8	...	...	48·5
Gram	89	23·4	1·1	54·3	5·1	5·1	15·5	14·7	0·7	50·5	2·9	5	15·1	71·0
Lentil	86	25·5	1·9	52·2	3·4	3·0	21·9	19·1	1·2	48·5	1·8	3	20·5	70·0
Husks	88	11·1	0·7	47·5	25·6	3·1	1·3	...	0·7	33·4	17·2	67	0·7	46·7
Pea	86	22·5	1·6	53·7	5·4	2·8	19·4	16·9	1·0	49·9	2·5	4	18·1	69·0
Husks	86	5·2	0·3	31·1	46·6	2·8	0·9	0·3	0·3	25·4	46·5	76	0·6	45·8
Oil Seeds, Cakes and Meals														
Coconut cake or meal	89	21·3	8·0	42·6	11·6	5·5	16·7	16·3	7·8	35·3	7·3	5	16·5	77·1
Cotton seed	91	18·7	21·5	25·6	20·5	4·7	12·8	11·5	18·7	12·8	15·5	6	12·2	77·2
Cake: Bombay	89	20·5	4·9	35·7	22·0	5·9	15·8	15·0	4·6	19·2	4·5	3	15·4	40·6
,, Egyptian	89	23·5	5·0	33·0	21·6	5·9	18·0	17·0	4·7	17·9	4·6	2	17·5	42·1
Cake or meal decorticated	90	42·0	7·9	26·0	7·7	6·4	36·2	34·7	7·5	17·4	2·2	2	35·5	68·6
Ground-nut	94	26·8	44·9	17·5	2·6	2·2	24·1	22·2	40·3	14·7	0·2	6	23·2	131·4
Cake: decorticated	89	46·4	7·4	23·0	6·4	5·8	41·7	40·3	6·7	19·5	0·5	2	41·0	72·5
,, undecorticated	89	30·0	9·0	21·6	22·7	5·7	27·5	26·6	8·1	18·3	2·6	2	27·1	56·4
Meal: extracted	92	31·6	1·9	29·0	25·2	4·3	29·1	28·2	1·5	19·9	2·9	2	28·7	44·2
Hemp seed cake	89	30·7	8·6	18·2	23·8	7·7	22·7	21·7	7·7	10·5	1·9	2	22·2	45·9
Kapok cake	89	27·8	7·3	20·8	26·6	6·5	20·6	18·5	6·6	10·4	5·3	2	19·6	40·4
Linseed	93	24·2	36·6	22·9	5·5	3·8	19·4	18·1	34·8	18·3	1·8	6	18·7	119·3
Cake: English	89	29·6	9·5	35·6	9·1	5·2	25·4	24·0	8·7	28·6	4·5	3	24·7	74·2
,, imported	89	32·3	9·9	32·2	8·7	5·9	27·8	26·3	9·1	25·8	4·3	3	27·0	74·5
Meal: extracted	90	36·4	3·2	34·6	9·2	6·6	31·5	30·1	2·9	27·8	4·6	2	30·8	65·1
Niger cake	89	32·3	5·8	23·4	18·1	9·4	25·9	23·3	4·7	19·7	4·9	2	24·6	51·4
Olive ,,	89	6·3	17·9	29·3	30·1	5·4	6·1	3·5	17·0	20·5	9·9	13	4·8	62·2
Palm kernels	92	8·5	49·0	26·9	5·8	1·8	8·0	7·8	46·7	22·6	3·5	18	7·9	144·2
Kernel cake: English	89	19·2	6·0	46·5	13·4	3·9	17·5	16·4	5·3	39·4	5·1	4	16·9	73·2
,, ,, imported	89	16·4	10·0	37·7	21·0	3·9	13·9	13·5	9·7	32·1	12·6	6	13·7	80·6
Meal: extracted	90	19·0	2·0	49·0	16·0	4·0	17·1	16·0	1·9	43·5	8·0	4	16·6	71·3
Poppy-seed cake	89	36·3	9·6	21·3	8·2	13·6	28·8	27·0	8·8	13·7	4·0	2	27·9	61·3
Rape seed	93	19·7	45·2	18·0	5·9	4·2	15·9	13·8	43·0	14·4	1·5	9	14·9	130·9
Cake	90	33·1	10·2	27·9	11·1	7·7	27·4	23·0	8·1	22·3	0·9	2	25·2	61·1

TABLE III.—COMPOSITION AND NUTRITIVE VALUE OF FEEDING STUFFS—*continued*

	Average Composition per cent. as shown by Analysis						Digestible Nutrients per cent.					Calculated from Digestible Nutrients		
				Carbohydrates						Carbohydrates			Per 100 lb.	
	Dry Matter	Crude Protein	Oil	Soluble	Fibre	Ash	Crude Protein	True Protein	Oil	Soluble	Fibre	App. Ratio S.E./P.E.	Protein Eqvt. (P.E.)	Starch Eqvt. (S.E.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Oil Seeds, Cakes and Meals—contd.														
Sesame seed	95	20·6	47·5	15·1	6·3	5·5	18·5	16·9	45·0	8·4	1·4	8	17·7	133·9
Seed cake: English	89	43·7	11·7	20·5	4·4	8·7	39·2	37·7	10·6	11·5	1·4	2	38·5	71·6
,, ,, imported	89	36·6	10·8	16·3	16·7	8·6	33·1	31·4	9·7	9·1	5·2	2	32·3	65·2
Seed meal: extracted	94	46·4	2·4	26·7	7·7	10·8	41·8	39·9	2·2	14·9	2·4	1	40·9	57·7
Soya bean	90	33·2	17·5	30·5	4·1	4·7	29·5	26·2	15·8	20·8	1·7	3	27·8	78·9
Bean cake	89	44·9	5·8	27·4	5·3	5·6	40·4	36·4	5·3	21·2	3·8	2	38·4	71·7
,, meal: extracted	90	45·3	1·5	32·4	5·2	5·6	40·9	36·8	1·4	25·1	3·7	2	38·9	65·0
Sunflower seed	93	14·3	32·5	14·6	28·2	3·4	12·9	11·2	30·8	10·4	9·4	9	12·1	104·3
Cake: decorticated	89	36·9	13·6	20·1	11·8	6·6	33·0	30·2	12·0	14·4	3·5	2	31·6	71·3
,, undecorticated	89	18·3	7·1	27·7	28·7	7·2	16·5	15·0	6·2	18·7	5·1	3	15·8	47·4
Animal By-products														
Blood meal	86	81·0	0·8	1·5	...	2·7	72·7	63·6	0·8	...	...	1	68·1	62·9
Fish meal: white	87	61·0	3·5	1·5	...	21·0	55·0	51·0	3·3	1·2	...	1	53·0	58·9
Meal: herring	87	64·1	8·4	4·2	...	10·3	59·5	55·7	7·7	3·4	...	1	57·6	75·7
Meat meal	89	72·0	13·2	...	...	3·8	67·0	63·4	12·5	...	...	1	65·2	90·8
Meal (low fat)	93	66·7	2·9	4·0	...	19·4	58·6	43·4	2·4	3·9	...	1	51·0	59·6
And bone meal	90	50·1	14·9	1·0	...	24·0	39·0	29·0	14·3	...	...	2	34·0	67·6
Milk, whole	12·8	3·4	3·9	4·8	...	0·7	3·2	3·2	3·9	4·8	...	6	3·2	17·1
Buttermilk	9·2	3·6	0·8	4·1	...	0·7	3·4	3·4	0·8	4·1	...	3	3·4	9·2
Separated	9·4	3·5	0·1	5·0	...	0·8	3·3	3·3	0·1	5·0	...	3	3·3	8·3
Skimmed	10	3·5	0·7	5·0	...	0·8	3·3	3·3	0·7	5·0	...	3	3·3	9·8
Whey	6·6	0·7	0·2	5·0	...	0·7	0·6	0·6	0·2	5·0	...	10	0·6	6·1
Miscellaneous														
Acorns	50	3·3	2·4	36·3	6·8	1·2	2·7	2·2	1·9	32·6	4·1	16	2·5	41·2

Apple pomace: fresh	25	1·4	1·1	16·6	4·6	1·3	0·7	0·5	0·5	11·5	...	20	0·6	12·0
Pomace: dried	89	4·0	3·5	52·3	27·4	1·8	1·6	1·2	1·7	36·6	1·7	23	1·4	32·6
Beech mast	89	13·3	27·5	25·5	18·5	4·2	10·7	10·1	24·2	16·8	7·4	9	10·4	86·3
Buckwheat	86	11·3	2·6	54·9	14·4	2·8	8·5	7·5	1·9	42·4	3·5	7	8·0	53·5
Cacao shells	90	18·8	11·2	36·4	15·5	8·1	0·8	...	9·4	17·5	3·3	97	0·4	39·0
Dreg meal	95	47·3	14·0	27·2	4·9	1·6	30·6	28·6	13·6	19·0	1·2	2	29·6	73·0
Gorse	50	5·2	1·1	17·6	23·4	2·7	2·1	1·5	0·5	10·6	9·4	5	1·8	8·7
Heather	50	3·5	4·3	16·6	22·7	2·9	1·4	0·7	1·5	8·6	7·0	6	1·0	6·0
Hops: spent, fresh	25	4·3	1·9	11·4	5·9	1·5	1·3	0·8	1·2	5·4	1·0	8	1·1	8·4
Spent, dried	89	15·3	6·8	39·5	21·0	6·4	4·7	3·0	4·4	18·9	3·6	8	3·8	29·7
Horse chestnuts	50	4·2	1·5	40·2	2·5	1·6	2·6	1·5	1·2	29·8	0·8	16	2·1	33·6
Locust bean	85	5·8	1·3	69·0	6·4	2·5	4·0	3·2	0·7	65·5	3·7	20	3·6	71·4
Molasses: beet	75	3·5	...	66·3	...	5·2	1·2	...	...	59·5	...	87	0·6	51·9
Cane	75	3·1	...	65·4	...	6·5	1·1	...	...	58·8	...	85	0·6	51·2
Potato slump (dry)	90	24·3	3·7	40·8	9·5	11·7	12·2	9·4	1·8	20·4	2·0	3	10·8	31·8
Tapioca	88	1·8	0·5	81·1	2·5	2·1	1·2	0·8	0·1	80·3	1·9	84	1·0	83·5
Yeast: dried	95	48·2	0·5	35·2	0·5	10·6	41·3	39·6	0·2	29·0	...	2	0·5	66·7
Swill: winter	25	3·7	3·0	14·5	1·4	2·4	2·3	1·6	2·3	13·9	0·8	13	2·0	18·5
Swill: summer	25	4·1	3·1	12·4	2·4	3·0	2·7	2·0	2·5	10·9	0·9	7	2·4	16·5

TABLE IV.—PERCENTAGE MINERAL COMPOSITION

	Ash	Calcium (CaO)	Phosphorus (P_2O_5)	Potassium (K_2O)	Chlorine (Cl)
Green Crops					
Pasture grass: leafy	2·5	0·35	0·20	0·75	0·24
Clover: early flowering stage	1·6	0·40	0·15	0·50	0·05
Lucerne: very young	1·8	0·45	0·13	0·48	0·05
Bud stage	1·8	0·77	0·14	0·56	0·05
Early flowering stage	2·4	0·96	0·12	0·43	0·08
Vetches: early flowering stage	1·5	0·50	0·15	0·50	...
Green Forage Crops					
Cabbage	1·2	0·20	0·15	0·40	0·02
Kale: marrow stem	1·8	0·41	0·11	0·52	0·20
Thousand-headed	1·7	0·39	0·13	0·52	0·16
Sugar-beet tops	3·3	0·35	0·11	0·60	...
Hays					
Clover	7·2	1·64	0·40	2·26	0·25
Meadow	6·8	1·10	0·47	1·76	0·41
Seeds	6·3	2·00	0·60	1·80	0·30
Lucerne	8·1	2·77	0·51	1·54	0·34
Roots					
Mangolds	0·8	0·02	0·08	0·40	0·14
Potatoes	1·0	0·03	0·18	0·60	0·04
Potato flakes: dried	3·8	0·09	0·43	2·41	0·33
Sugar-beet pulp: dry	3·1	1·20	0·18	0·59	0·05
Molassed	5·5	1·20	0·17	1·34	0·48
Swedes	0·7	0·08	0·08	0·30	0·04
Straws					
Bean	4·6	1·20	0·30	1·90	...
Oat	4·9	0·36	0·18	1·50	0·30
Pea	6·5	1·60	0·40	1·00	...
Wheat	5·3	0·29	0·13	0·80	0·20
Cereals and Cereal Products					
Barley	2·6	0·07	0·84	0·57	0·12
Brewers' grains, dried	3·9	0·40	1·60	0·20	0·06
Distillers' ,, ,,	1·8	0·40	0·68	0·20	0·06
Maize	1·3	0·02	0·82	0·40	0·07
Flaked	0·9	Trace	0·60	0·25	Trace
Germ meal	3·6	0·10	0·90	1·30	...
Gluten feed	2·5	0·10	0·70	0·20	...
,, meal	1·1	0·05	0·30	0·05	...

OF SOME COMMON FOODS

	Ash	Calcium (CaO)	Phosphorus (P_2O_5)	Potassium (K_2O)	Chlorine (Cl)
Cereals and Cereal Products—contd.					
Oats	3·1	0·14	0·81	0·55	0·07
Rice meal	8·6	0·10	2·50	0·70	0·14
Wheat	1·7	0·05	0·86	0·60	0·08
Middlings, coarse	3·7	0·10	2·67	1·44	0·03
Bran	5·8	0·20	2·80	1·50	0·09
Leguminous Seeds					
Beans	3·2	0·18	0·88	1·28	0·03
Peas	2·8	0·10	0·80	1·00	0·04
Oil Seed Cakes and Meals					
Coconut	5·5	0·51	1·53	2·04	...
Cotton cake, undecorticated	5·9	0·30	2·54	1·62	0·05
Seed meal, decorticated	6·4	0·38	2·88	1·70	0·04
Ground-nut cake: decorticated	5·8	0·20	1·00	1·50	0·03
Ground-nut cake: undecorticated	5·7	0·20	1·00	1·10	...
Linseed cake	5·2	0·51	1·70	1·30	0·09
Palm kernel cake	3·9	0·31	1·13	0·51	0·16
Soya bean cake	5·6	0·32	2·11	1·90	0·03
Meal: extracted	5·6	0·30	2·14	1·94	0·03
Animal By-products					
Blood meal	2·7	0·05	0·22	0·31	0·85
Fish meal, white	21·0	9·56	8·59	1·15	0·96
Meat meal	3·8	0·40	0·70	0·10	0·27
(Low fat)	19·4	8·42	7·35	0·72	1·23
And bone meal	24·0	10·50	9·30	0·80	1·40
Milk, whole	0·7	0·15	0·17	0·17	0·09
Separated	0·8	0·15	0·20	0·20	0·10
Whey	0·7	0·10	0·10	0·15	0·07
Miscellaneous					
Heather	2·9	0·52	0·31	0·50	0·10
Locust bean	2·5	0·85	0·26	0·70	0·20
Tapioca	2·1	0·21	0·24	0·99	0·02
Yeast, dried	10·6	0·30	5·51	2·00	...
Swill, winter	2·4	0·23	0·18	...	0·19
Summer	3·0	0·28	0·22	...	0·23

TABLE V

APPROXIMATE LIVE WEIGHTS (LB.) OF COMMERCIAL ANIMALS

Live Weights show Great Variations according to Breed and Feeding

CATTLE

(1) *Young Stock*

Age in Months	Beef Steer (full growth with fattening)	Beef Steer (full growth without fattening)	Smaller Dairy Type (Heifer)
0	80	80	70
3	200	170	150
6	400	350	220
9	560	480	290
12	700	600	360
15	830	720	430
18	950	840	510
21	1080	950	580
24	1200	1060	660
27	...	1170	750
30	...	...	850

(2) *Mature Animals, in breeding condition*

Cows			Bulls		
Smaller Dairy Breeds	Larger Dairy Breeds	Average Beef Breeds	Smaller Dairy Breeds	Larger Dairy Breeds	Average Beef Breeds
1000	1250	1350	1250	1600	1800

SHEEP

(1) *Young Stock*

Age in Months	Large Lowland (for sale as Lambs)	Large Lowland (for sale as Tegs)	Medium Breeds and Cross-breds (for sale as Tegs)	Small Upland Breeds
0	10	10	8	5
1	30	25	18	12
2	50	41	32	20
3	70	58	45	28
4	90	75	57	38
5	...	90	67	46
6	...	105	76	53
7	...	120	86	62
8	...	...	95	70
9	...	...	104	80
12	...	...	...	100

TABLE V.—*continued*

(2) *Mature Sheep, in breeding condition*

Ewes			Rams		
Small Upland Breeds	Medium Breeds and Crosses	Large Lowland Breeds	Small Upland Breeds	Medium Breeds and Crosses	Large Lowland Breeds
110	150	200	150	220	280

PIGS

(1) *Young Stock*

Age in Months	Pork Type	Bacon Type	Young Breeding Stock
0	3	3	3
1	14	14	14
2	32	32	32
3	55	50	42
4	85	80	67
5	120	115	97
6	...	155	130
7	...	200	165
8	...	245	200
9	...	...	230
12	...	...	280

(2) *Mature Pigs, in breeding condition*

Sows		Boars	
Small Breeds	Large Breeds	Small Breeds	Large Breeds
350	450	450	600

HORSES

Age in Months	Draft Colt
0	200
3	500
6	700
12	900
18	1150
24	1300
30	1400

Mature Horses, in breeding condition

Cab Horse	Farm Horses			Draft Stallions
	Small	Medium	Large	
1000	1200	1400	1700	1900

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